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THESIS

PROCESSING, MICROSTRUCTURE AND ELEVATED TEMPERATURE MECHANICAL PROPERTIES OF A 6061 ALUMINUM - ALUMINA METAL MATRIX COMPOSITE

by

Paul D. Macri

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Thesis Advisor Terry R. McNelley
Co-Advisor Peter N. Kalu

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A study was conducted on the effects of thermomechanical processing by warm rolling of a cast, aluminum-based discontinuous metal matrix composite. The material studied was a 6061 aluminum containing 10 or 15 volume percent alumina (Al_2O_3) particles. The material was cast and extruded by DURALCAN Inc. of San Diego, California. The subsequent processing included rolling at either 250°C or 350°C with reheating and annealing always at 350°C. The microstructure was studied by both optical and transmission electron microscopy. A significant improvement in the distribution of the Al_2O_3 particles was achieved by the thermomechanical processing. It is also shown that a substantial grain refinement (from a grain size of 500 μm to 20 μm) accompanied the improved particle distribution. The elevated temperature ductility and strength did not differ significantly with volume percent of Al_2O_3 added. Also, the details of the thermomechanical processing did not effect the strength at higher temperatures.

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Processing, Microstructure and Elevated Temperature Mechanical Properties of a 6061 Aluminum - Alumina Metal Matrix Composite

by

Paul D. Macri
Lieutenant, United States Navy
B.S., Pennsylvania State University, 1983

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ABSTRACT

A study was conducted on the effects of thermomechanical processing by warm rolling of a cast, aluminum-based discontinuous metal matrix composite. The material studied was a 6061 aluminum containing 10 or 15 volume percent alumina (Al_2O_3) particles. The material was cast and extruded by DURALCAN Inc. of San Diego, California. The subsequent processing included rolling at either 250°C or 350°C with reheating and annealing always at 350°C. The microstructure was studied by both optical and transmission electron microscopy. A significant improvement in the distribution of the Al_2O_3 particles was achieved by the thermomechanical processing. It is also shown that a substantial grain refinement (from a grain size of 500 μm to 20 μm) accompanied the improved particle distribution. The elevated temperature ductility and strength did not differ significantly with volume percent of Al_2O_3 added. Also, the details of the thermomechanical processing did not effect the strength at higher temperatures.

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I. INTRODUCTION

In recent years there has been a growing scientific, industrial and military interest in the development of metal matrix composites (MMCs). MMCs offer an increase in modulus, tensile and compressive strengths greater than their unreinforced counterparts, improved friction and wear characteristics, reduced thermal expansion coefficients and other property combinations not obtainable in monolithic materials. A MMC offers an advantage over polymeric based composites in high temperature applications and also possesses improved stability with respect to vacuum and ultraviolet radiation [Ref. 1].

Composite materials are popular because one can design a new material to have a desired set of properties not found in any single existing material. The three categories of composites are: particulate; continuous fiber; and whisker reinforced composites. When using particles that are uniformly distributed, the composite will have isotropic properties, unlike the fiber- and whisker-containing materials. These particles may interact with dislocations or otherwise alter microstructure and thus cause an increase in strength [Ref. 2].

Cast ceramic-particle reinforced Aluminum alloy composites are available in production quantity. They can be shaped by conventional metal working processes such as extrusion, rolling and forging. Al 6061 with Alumina (Al_2O_3) is relatively easy to fabricate using casting methods. The wetting of the matrix material to particles is better with Al_2O_3 than with SiC. Adding large particles (3-50 μm) increases the modulus of elasticity. Also, there is no chemical reaction or need for adherent-corrosive protection of Al_2O_3. However, the as-cast Al 6061 - Al_2O_3 material has poor ductility.

Dural Aluminum Composites Corporation (DURALCAN), based in San Diego, California, has developed a proprietary casting process. Their pretreatment process prevents the molten aluminum from chemically reacting with the particles while still ensuring adequate wetting. The pretreatment also reduces dissolved gases [Ref. 3]. DURALCAN produces castings of Al 6061 with 10 to 20 volume percent (vol. pct.) Al_2O_3 up to eleven inches in diameter. They produce shafts, bars, rectangles and tubes. Their production capacity will increase to 25 million pounds with the opening of a plant in Canada [Ref. 4]. With the high production capacity and excellent potential properties, there is a growing need for further research of MMC's.

This study is primarily microstructural in nature. The purpose of this thesis was to study the effect of the thermomechanical processing on the evolution of the microstructure and the development of mechanical properties in a 10 or 15 vol. pct. Al_2O_3 in 6061 Aluminum composite material.

II. BACKGROUND

A. THE MATRIX ALLOY

The matrix material is usually tough and ductile while the particulate addition is comparatively brittle. The matrix supports the particles, allows the load to be transmitted to the particles and prevents the cracks formed in particles from propagating through the entire structure. The matrix itself should be strong to contribute to the overall strength of the composite. Matrices of composites are either polymers, ceramics or metals. The polymeric composites are useful at relatively low temperatures. Ceramics are hard and brittle, but have good properties at very high temperatures. Most MMC's can operate at high temperatures, but production is more expensive than with a polymeric matrix. [Ref. 2]

Discontinuously reinforced Aluminum MMC's offer a higher stiffness per unit weight as compared to unreinforced alloys. Cast Aluminum MMC's have a large cost advantage over those processed via powder metallurgical methods. [Ref. 5] The subject of this research is a 6061 Aluminum alloy matrix. The 6XXX series (Al-Mg-Si alloys) is amenable to heat treatment in order to improve mechanical properties. The 6XXX series combines medium strength, good ductility, formability and weldability with minor property losses along with good corrosion resistance. See Table 1 [Ref. 6].

Table 1. PROPERTIES OF UNREINFORCED ALUMINUM ALLOYS

Alloy	Nominal Composition	Density g/cm^3	Elastic Modulus GPa	Yield Strength MPa	Ultimate Tensile Strength MPa	Failure Strain, Percent
2024 Al	4.4 Cu-1.5 Mg -0.6 Mn	2.77	72.4	414	483	13
5083 Al	4.5 Mg-0.35 Mn	2.66	69.3	234	317	12
6061 Al	1.0 Mg-0.28 Cu -0.2 Cr-0.6 Si	2.70	68.3	276	310	17
7075 Al	5.6 Zn-2.5 Mg -1.6 Cu-0.23 Cl	2.80	71.0	503	572	11

Al 6061 is typically tempered to a T4 or T6 condition. The T4 is solution heat treated and naturally aged to a substantially stable condition while the T6 is solution heat treated and then artificially aged [Ref. 7]. The 6061 alloy is often formed via extrusion. This hot working process is illustrated schematically in Figure 1 [Ref. 6]. Extrusion may involve area reductions as large as 25:1, corresponding to true strains of approximately 3.2 or more, in a single operation.

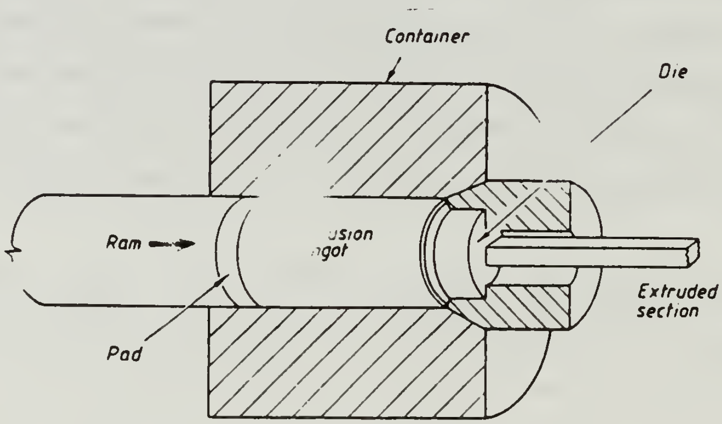

Figure 1. Extrusion of a metal

B. THE REINFORCEMENT

There are four types of materials that offer competition to discontinuous MMC's (DMMC). They are:

- Polymer based composites such as carbon fiber reinforced plastic (CFRP);
- Unreinforced, powder based metallic material (PM);
- Continuous fiber reinforced MMC's;
- Other cast or wrought metallic alloys.

The three types of DMMC reinforcements are short fibers (3μm diameter, $\leq$ 50 μm long), whiskers ($\leq$ 1 μm diameter, < 40 μm long) and particles (3-40 μm diameter). This study involves the particulate type DMMC. DMMC's offer a smaller gain in mechanical properties, while still having isotropic behavior, as compared to continuous fiber com-

posites. In aluminum alloys it has been demonstrated that the following variables influence the microstructure of the alloy:

- the size and shape of the reinforcement;
- the volume fraction of the reinforcement;
- the processing route for the composite;
- the relative coefficient of expansion of reinforcement and matrix;
- the type of alloy. [Ref. 8]

The Al_2O_3 particles added are approximately 10 μm in diameter and irregularly shaped. The volume fractions were 0.10 and 0.15. The coefficients of expansion for Al_2O_3 and Aluminum are 6.7 and 25 $x10^{-6}$ cm/cm-°C, respectively, which is a factor of four difference [Ref. 2]. Table 2 shows the properties of various reinforcements for metal matrix composites [Ref. 9]. The properties of the various forms of reinforcement (particulate and fiber) can be compared.

Table 2. REINFORCEMENT FOR LIQUID-METAL INFILTRATION

	Strength (MPa)	Modulus (GPa)	Density (g/cm^3)	ε %	Diameter (μm)
Al_2O_3 (Saffil)	2000	300	3.3	0.67	3
Al_2O_3 (FP)	1380	379	3.9	0.36	20
Continuous SiC (Nicalon)	2760	200	2.55	1.5	10-15
SCS-2	3450	407	3.05	0.8	140
Carbon P-55	2068	380	2.25	0.5	10
P-75	2068	517	2.25	0.42	10
P-100	2240	690	2.25	0.5	10

C. THE COMPOSITE

There are at least five problems to be dealt with in casting a MMC materia. hese are:

- wetting
- dispersion
- inclusions
- porosity
- segregation.

Difficulty in wetting increases as the particle size decreases. This is due to the increased surface energy required as the particle penetrates through the liquid metal surface and thus finely divided powders tend to cluster together face treatment of particles may be necessary to obtain particle wetting and thereb ieve an even distribution when composites are produced via the melt stirring route. niform dispersion is important for isotropy of properties. Inclusions, like oxide film on the surface, should be avoided. Aluminum will extract hydrogen from moisture in the environment. Hydrogen has a high solubility in liquid Aluminum. Inclusions in the melt provide nucleation sites for hydrogen bubbles which result in porosity. Dendritic segregation can cause clustering even though the particles may have been thoroughly dispersed in the melt. During freezing, a dendritic arm that encounters a second phase particle will either entrap it or push it aside. When freezing is complete, the particles pushed aside will be segregated into dendrite interstices [Ref. 10]. DURALCAN's pretreatment in their proprietary casting process prevents a chemical reaction between the particles and the matrix alloy while still ensuring ade uate wetting, and reducing dissolved gases.

In the past, 6061 has had various applications in cars, trucks and marine superstructures. The Navy has an interest in developing the 6061 MMC for use in bulkhead doors and related applications. They would be light, stiff and have a high thermal conductivity. There are now possibilities that MMC's based on 6061 can have primary and secondary structural applications in the aerospace industry [Ref. 11]. MMC's have already been qualified for space flight as booms for the Space Telescope. There is also an interest in using MMC's on satellites as shields against pellet, nuclear or laser weapons [Ref. 12].

D. POST CONSOLIDATION TREATMENT OF METAL MATRIX COMPOSITES

The purpose of post-fabrication processing is to develop a homogeneous distribution of the particles throughout the matrix. DMMC's are sensitive to the distribution of the particles. The clustering of the particles causes a lowering of the strength and ductility of the composite. A common method, used for this material, is extrusion. However, other forms of treatment may involve forging or rolling.

It has been recognized that a single warm temperature deformation process coupled with prolonged annealing gives a different microstructure from a sequential deformation /anneal/deformation/anneal process as used in this study. Further refinement of an extruded composite can be accomplished using rolling. The rolling portion of the TMP involved nine warm-rolling passes with increasing strain per pass, and used two different annealing and rolling temperatures. The ambient properties of ductility and fracture toughness were the focus of work by Schaefer who examined the properties of this material in the as-extruded condition with subsequent TMP by warm rolling [Ref. 3]. The intent of the TMP was to improve the distribution of the Al_2O_3 in the matrix and to refine the grain size by the conclusion of processing. This thesis investigated elevated temperature testing of similarly processed materials.

III. EXPERIMENTAL PROCEDURE

A. MATERIAL AND SECTIONING

DURALCAN provided two samples of 6061 Aluminum with Al_2O_3 added. One contained 10 vol. pct. and the other 15 vol. pct. of Al_2O_3. The MMC material was obtained in both the as-cast and as-extruded conditions.

The extruded rectangular bar had rounded corners and nominal dimensions 76 mm x 19 mm (3.0 in x 0.75 in). Two sections were cut using a power hack saw to dimensions of 38 mm x 66 mm x 19 mm (1.5 in x 2.6 in x 0.75 in) for use as rolling billets. [Ref. 3] An extra piece was processed with the first two and had smaller sections cut from it at intermediate stages of the rolling process in order to facilitate optical and transmission electron microscopy (TEM) for microstructural analysis.

B. THERMOMECHANICAL PROCESSING

In previous work by Schaefer [Ref. 3] and Magill [Ref. 13] it was recommended that TMP be conducted using a rolling temperature of 250°C, with annealing between passes at this same temperature. This was based on the observation of increased ductility during elevated temperature testing following a reduction in the rolling temperature from 500°C to 350°C [Ref. 13].

Billets for processing were always solutionized at 560°C for 90 minutes in a Lindberg type B-6 Heavy Duty Furnace to ensure homogeneity of the matrix. The billets were then water quenched to room temperature. The subsequent processing trials are described below.

Initial attempts to roll at 250°C were unsuccessful as the billets split at their mid-plane (alligatoring). A second series of processes were then conducted utilizing a rolling temperature of 250°C but with annealing at 350°C for varying lengths of time. It became apparent as well that the rolling schedule required modification to reduce the strain per pass in the early stages of rolling.

The rolling schedule used in most of the work is designated TMP 1 and is summarized in Table 3. A modified version is summarized in Table 4. The results of the rolling trials are summaried in Table 5 for the Al-6061 10 vol. pct. Al_2O_3 material in Table 6 for the Al-6061 15 vol. pct. Al_2O_3 material. Essentially, four of the seven combinations of Al_2O_3 content and TMP (designated subsequently as samples A, C, F and G) provided material for the remainder of this research.

Table 3. ROLLING SCHEDULE FOR TMP 1

ROLL #	ROLL CHANGE (0.08in + 0.01in)	MILL SETTING (left/right)	MILL GAP (in)	SILICONE LUBRICANT
1	+(8 + 0)	4/4	0.64	NO
2	-(1 + 2)	2/2	0.54	NO
3	-(1 + 2)	0/0	0.44	NO
4	-(1 + 2)	6/6	0.34	NO
5	-(1 + 2)	4/4	0.24	YES
6	-(0 + 6)	6/6	0.18	YES
7	-(0 + 6)	0/0	0.12	YES
8	-(0 + 5)	3/3	0.07	YES
9	-(0 + 2.2)	0.8/0.8	0.048	YES

Table 4. MODIFIED ROLLING SCHEDULE FOR TMP 2

ROLL #	ROLL CHANGE (0.08in + 0.01in)	MILL SETTING (left/right)	MILL GAP (in)	% STRAIN (per pass)
1	+(8 + 5)	1/1	0.72	4.0
2	-(1 + 0)	1/1	0.64	11.1
3	-(1 + 2)	7/7	0.54	15.5
4	-(1 + 2)	6/6	0.44	18.5
5	-(1 + 1)	5/5	0.35	21.5
6	-(1 + 1)	4/4	0.26	25.7
7	-(0 + 7)	7/7	0.19	26.9
8	-(0 + 6)	1/1	0.13	31.6
9	-(0 + 5)	4/4	0.08	38.5
10	-(0 + 3.2)	0.8/0.8	0.048	40.0

Table 5. PROCESSING SCHEDULE FOR 6061 AL-ALUMINA 10 VOL. PCT.

Roll and Anneal Temps	10% Vol		
	Size of Billet	Strain per roll	Comments
Sample A Anneal @ 350°C (30 min) Roll @ 250°C (5 min) (TMP 1)	0.75″ x 1.5″ X 2.6″ (l/w ≈ 1.6)	1 14.7 2 15.6 3 18.6 4 22.7 5 29.4 6 25.0 7 50.0 8 41.7 9 31.4	Partial split @ 2nd,3rd, and 4th rolls no further splitting
Sample B Roll/Anneal @ 250°C (30 min) (TMP 1)	0.75″ x 1.5″ X 2.6″ (l/w ≈ 1.6)	1 14.7 2 15.6 3 18.6 4 22.7 5 29.4 6 25.0 7 50.0 8 41.7 9 31.4	"alligator" Complete split after 2nd roll no further assesment of material
Sample D Roll/Anneal @ 250°C (30 min) (TMP 2)	0.75″ x 1.4″ X 5.7″ (l/w ≈ 4.0)	1 4.0 2 11.1 3 15.5 4 18.5 5 21.5 6 25.7 7 26.9 8 31.6 [illegible] 38.5 10 40.0	"alligator" Complete split after 2nd roll no further assesment of material
Sample F Roll/Anneal @ 350°C (60 min) (TMP 1)	0.75″ x 1.4″ X 5.7″ (l/w ≈ 4.0)	1 14.7 2 15.6 3 18.6 4 22.7 5 29.4 6 25.0 7 50.0 8 41.7 9 31.4	No splitting

Table 6. PROCESSING SCHEDULE FOR 6061 AL-ALUMINA 15 VOL. PCT.

Roll and Anneal Temps	15% Vol		
	Size of Billet	Strain per roll	Comments
Sample C Anneal @ 350°C (30 min) Roll @ 250°C (5 min) (TMP 1)	0.75" x 1.4" X 5.5" (l/w ≈ 4.0)	1 14.7 2 15.6 3 18.6 4 22.7 5 29.4 6 25.0 7 50.0 8 41.7 9 31.4	No splitting
Sample E Roll/Anneal @ 250°C (30 min) (TMP 2)	0.75" x 1.4" X 5.7" (l/w ≈ 4.0)	1 4.0 2 11.1 3 15.5 4 18.5 5 21.5 6 25.7 7 26.9 8 31.6 9 38.5 10 40.0	"alligator" Complete split after 3rd roll no further assesment of material
Sample G Roll/Anneal @ 250°C (60 min) (TMP 1)	0.75" x 1.4" X 5.7" (l/w ≈ 4.0)	1 14.7 2 15.6 3 18.6 4 22.7 5 29.4 6 25.0 7 50.0 8 41.7 9 31.4	Partial split @ 3rd roll no further splitting

C. MACHINING

A diamond-tipped cutting tool reduced the amount of tool wear while cutting the harder 15 vol. pct. samples. The tension test coupons were machined to the specifications given in Figure 2.

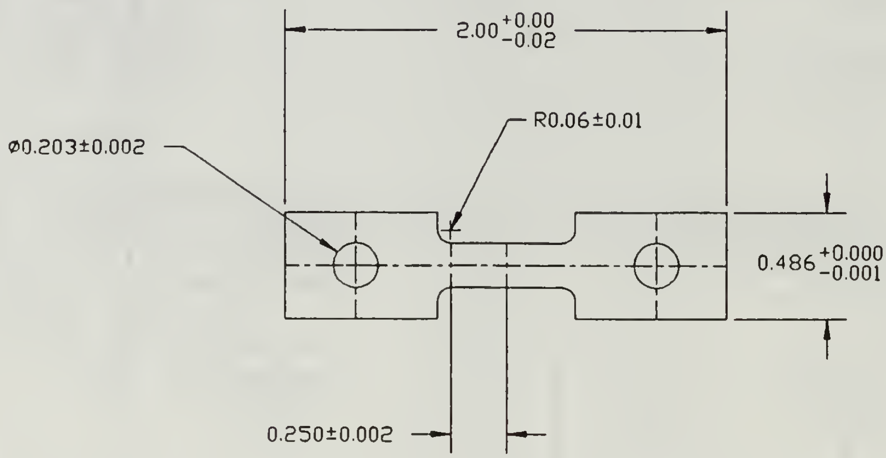

Figure 2. Dimensions and tolerances for tensile test specimens.

D. TENSILE TESTING

The tensile load cell output of an Instron Model 6027 test machine was fed into a Hewlett Packard Model 3852A Data Acquisition Unit which produced load vs. time graphs. The tests were performed at 350°C using a Marshall Model 1137 Furnace rated to 1100°C and controlled by a Eurotherm Model 199 temperature controller. There were five thermocouples used to monitor the temperature of the test sample. One was at the center of the coupon while the other two pairs were one-half inches above and below the centerline of the sample. The crosshead speed was maintained at either of two different strain rates, corresponding to 5.08 or 50.8 mm/min. The nominal strain rates were $6.7x10^{-3}s^{-1}$ and $6.7x10^{-2}s^{-1}$, respectively. Self-aligning grips were used to hold the tensile test specimens as in Figure 3 [Ref. 14].

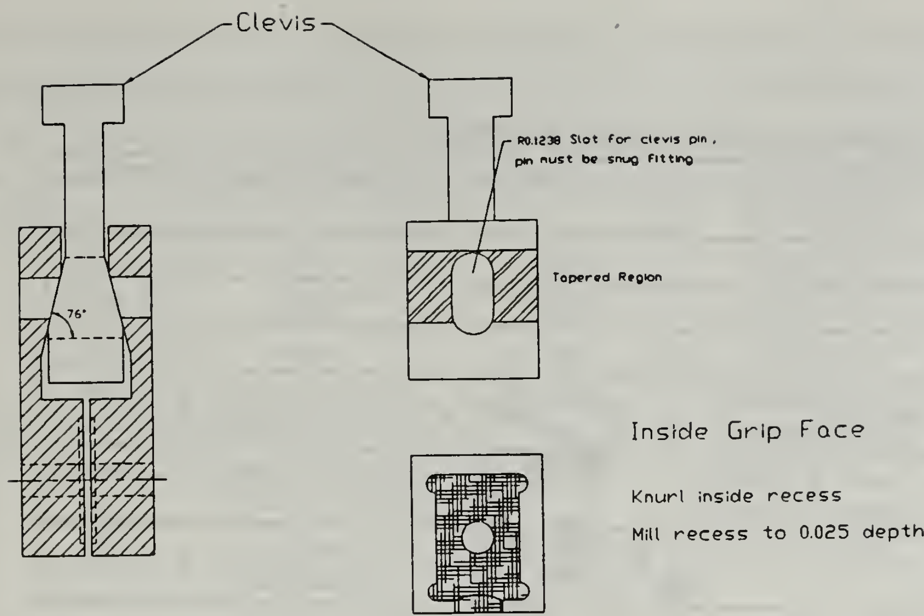

Figure 3. Self-aligning grip assembly for tensile test.

E. DATA REDUCTION

Programs were developed for the HP-9000 computer for data analysis. Load vs. time data was collected during the tensile testing. To correct for grip slippage, the slope of the elastic region of the load vs. time graph was calculated. The horizontal displacement from the elastic line on the load-time graph was used to determine and plot the engineering stress vs. engineering plastic strain. The software is in the developmental stages and the program codes for data acquisition and data reduction are enclosed in Appendix A.

F. OPTICAL MICROSCOPY

The samples were mounted in Buehler Sampl-Kwick thermoset plastic. The samples were cleaned with detergent, rinsed and dried between steps. Plastic gloves were worn when using the OPS colloidal silica due to its caustic nature. For steps four through six on Table 7, Plan, Mol and OP Chem papers, respectively, were used on the polishing wheels. These papers yielded a significant improvement in the quality of the prepared samples.

Table 7. OPTICAL SAMPLE PREPARATION

STEP #	POLISHING MEDIUM	LOAD/RPM	LUBRICANT	TIME
1	240 GRIT	light/ -	water	2 min
2	400 GRIT	light/ -	water	2 min
3	600 GRIT	light/ -	water	2 min
4	6 μm diamond paste (Metadi)	light/150	DP Lubricant Red (Struers)	3 min
5	3 μm diamond paste (Metadi)	light/150	DP Lubricant Red (Struers)	2 min
6	colloid ilica	light/150	Beulers Mastemet	2 min

Once the micrographs were obtain to r eal the distribution of the Al_2O_3 reinforment, the optical-microscopy samples were anodized to examine the microstructure of the matrix. The etchant was a modified Barker's reagent (HBF_4 (48% solution), 46 cm^3; boric acid, 79 cm^3; H_2O , 970 cm^3) [Ref. 15].

G. TRANSMISSION ELECTRON MICROSCOPY

The material sectioned after each rolling pass was saved for optical and Transmission Electron Microscope (TEM) work. The TEM samples were 3.0 mm disks, 0.2 mm thick, and cut by a Metals Research, Ltd., S.M.D. Servomet rk Machine. The samples were mechanically polished down to a thickness of about m and dimpled to about 26 μm on a Gatan dimple rinder, Model 656. The samples re finally thinned in a Gatan Dual Beam Ion Mill Model 600 at an accelerating voltage of 6 KV and a gain current of about 100 microamps.

H. DISTRIBUTION OF ALUMINA PARTICLES

A video camera was attached to the eye piece of an Zeiss ICM 405 optical microscope. The field of view of the sample at a magnification of 540X was displayed on a Sony model PVM-1343MD color video monitor. The MicroScience *ImageMeasure*® version 4.02 software package was used to determine the volume percentage of the Al_2O_3 . Each pixel was assigned a shade value from 0 to 255, with black being zero, white, 255, and the shades of grey ranged from 1 to 254. The matrix (Al) ranged from 0-70 and the particles (Al_2O_3) had shades of grey of approximately 62 at the edges to about 92 at

the center. The contrast bias was used to cancel all lighter shades from 92 to 255. This allowed only the particles themselves to be depicted on the screen with a totally white background. This allowed the program to determine the particles as a percentage of the total field of view. A hard copy of the screen is illustrated in Figure 4 which shows an actual particle percentage of 15.7% for the 15 vol. pct. sample.

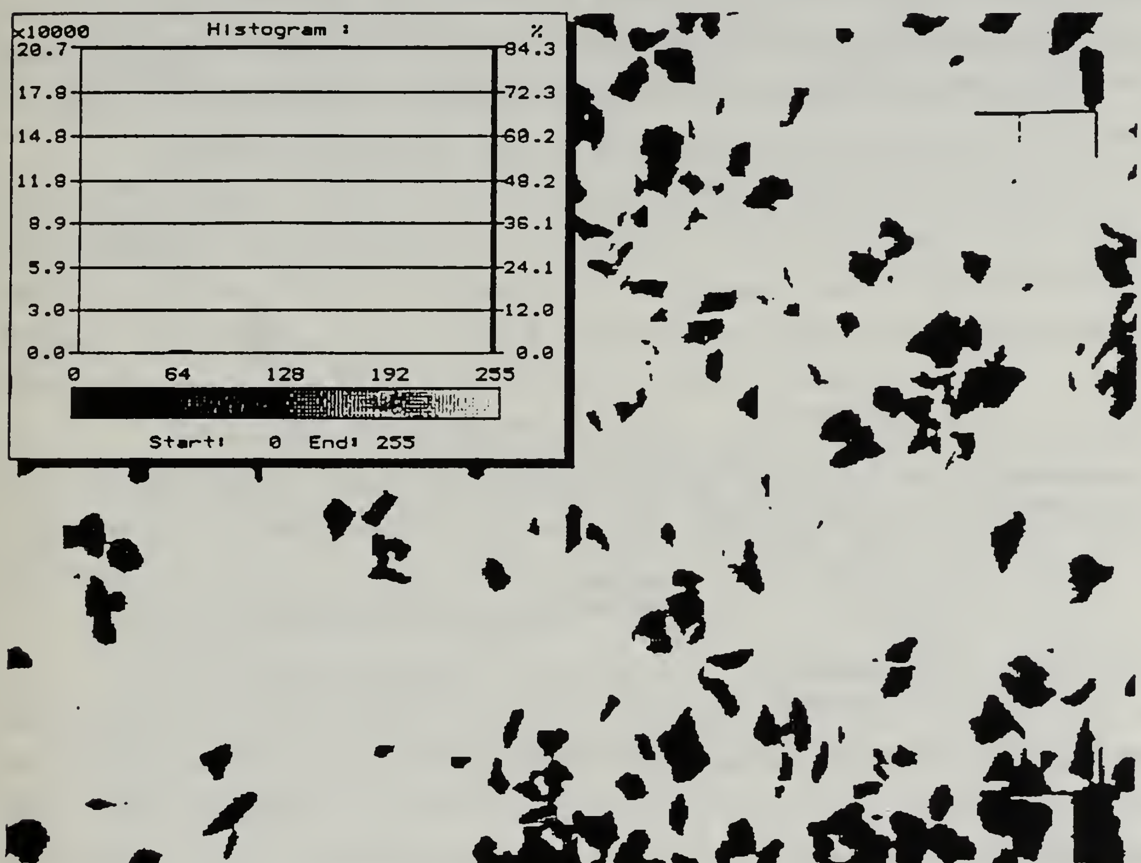

Figure 4. Software display of distribution of Al_2O_3

IV. RESULTS AND DISCUSSION

A. AS EXTRUDED CONDITION

The extruded bar was sectioned to examine the transverse, top and longitudinal surfaces as shown in Figure 5 [Ref. 16]. The top surface was examined in the as-extruded sample by optical microscopy and samples were prepared subsequently after each rolling pass. Figure 6 shows the clustering of particles with some banding. On this scale it is not readily apparent that the particles are not randomly distributed. The arrows show examples of where particles are clustered together next to an area lacking particles.

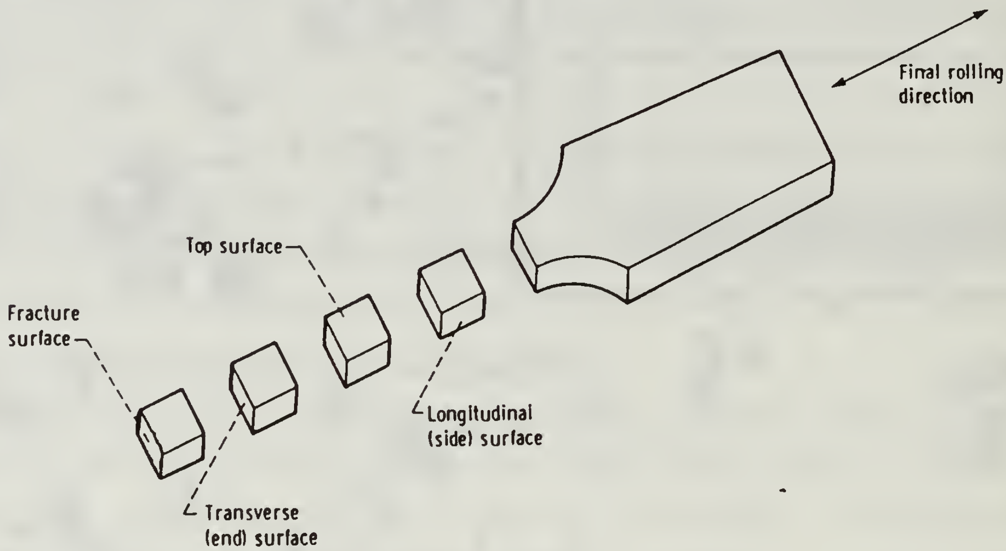

Figure 5. Code system for specimen orientation [Ref. 16].

B. PROCESSED CONDITIONS

1. Effects of Processing on Microstructure

a. Size and Distribution of Particles

The development of the microstructure was characterized at three different stages: the initial stage (rolling passes one to three), the intermediate stage (rolling passes four to seven), and the final stage (rolling passes eight and nine). All the following micrographs show the results for material processed by TMP 1. After the first rolling pass on sample A (10 vol. pct. Al_2O_3), the particle distribution can be seen in Figure 7. There is clustering of particles with areas that are apparently devoid of particles. Less

banding is apparent when compared to the extruded condition. In the initial rolling passes, there is an increase in strain in each suceeding pass of the TMP and the particle clusters are being dispersed. However, while the clusters are being broken up, the particles themselves remain intact. At higher magnifications, the extent of the clustering is more evident. Figure 8 shows the clustering of particles after the first rolling pass. At this magnification (540 X) the tight grouping of the particles is clearly seen with other areas having few particles. During the intermediate stage, as can be seen in Figure 9. clusters are "smeared" into a banded structure. Figure 10 shows that the clusters themselves are being broken up to some extent. After the ninth pass, a fairly random distribution of the particles have been achieved as shown in Figure 11 and Figure 12.

A similar development through the rolling can be seen in sample C (15 vol. pct. Al_2O_3). Figure 13 shows the structure after rolling pass two. In Figure 14, after rolling pass five, the banding in the structure is more apparent. Figure 15 is just prior to rolling pass nine. There are still remnants of the banding but the tight clusters from the extruded condition are gone. Indeed, looking at rolling pass one and comparing to rolling pass nine there is a subtle change in the particle distribution.

The particle size remains the same throughout. The particles are not fractured into finer pieces. The distribution of particles changes from a random distribution of clusters to a banded structure, and finally to a more evenly dispersed, less banded structure.

b. Recrystallization of the Matrix

It is evident from Figure 16 and Figure 17 that substantial grain refinement has resulted as well from the TMP. Compare the grain size of about 500 μm after the third rolling pass on sample C (15 vol. pct. Al_2O_3) to about 20 μm after rolling pass eight. This sample was annealed as well for 30 mins at 350°C after pass number eight. The microstructure at the early stages of processing (see Figure 16) is not well defined except at the neighborhood of the particles where the localized contrast suggests the formation of local lattice rotation. These highly deformed sites in turn help to promote particle-stimulated nucleation during annealing, as shown in Figure 18. It is highly probable that this mechanism is the key to the grain refinement. Further evidence to confirm the

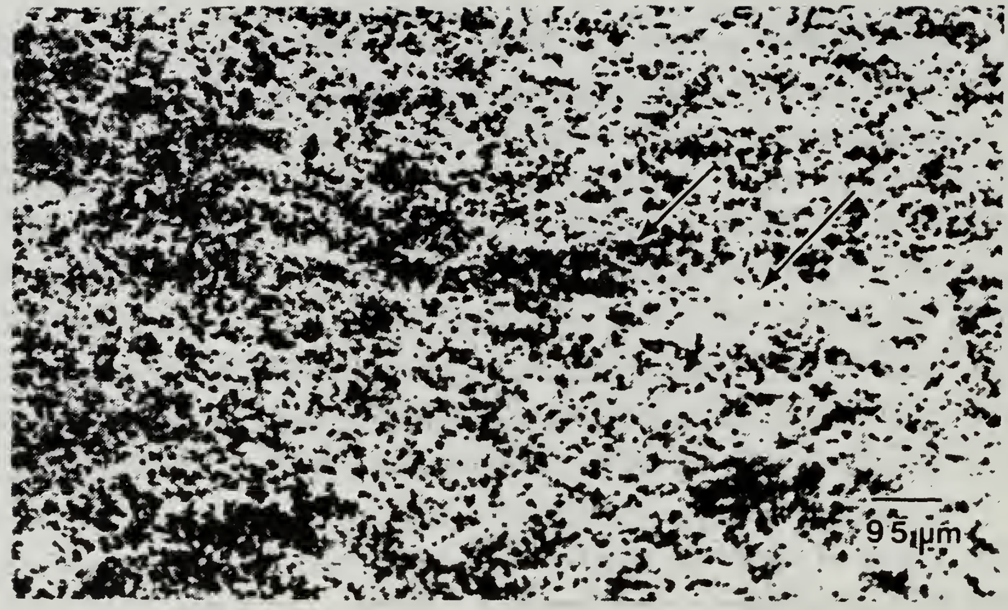

Figure 6. As-extruded top surface orientation of 10 vol. pct. Alumina (108X)

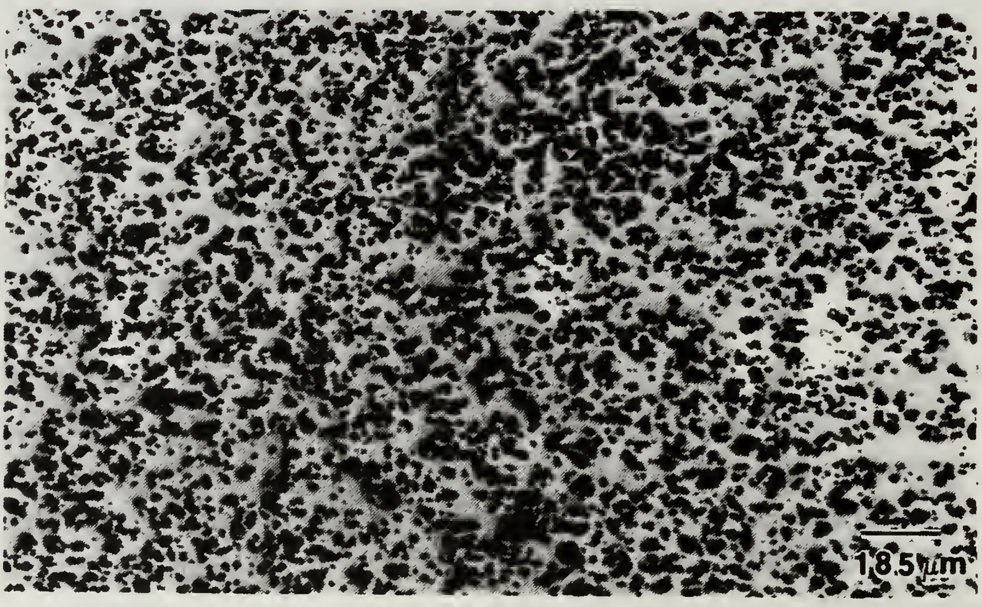

Figure 7. Sample A after rolling pass one, 10 vol. pct. Alumina (54X).

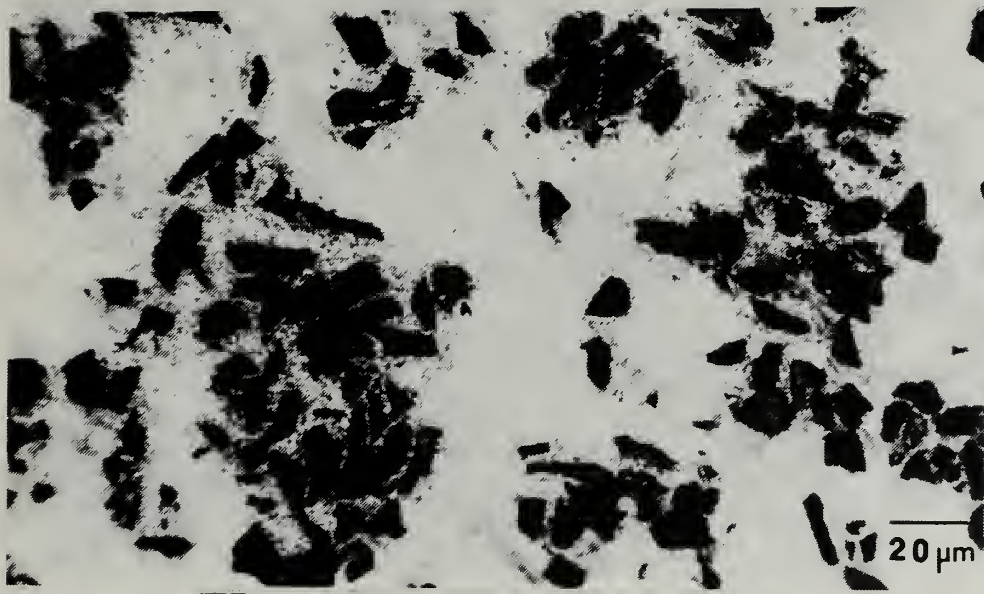

Figure 8. Sample C after rolling pass one, 15 vol. pct. Alumina (540X).

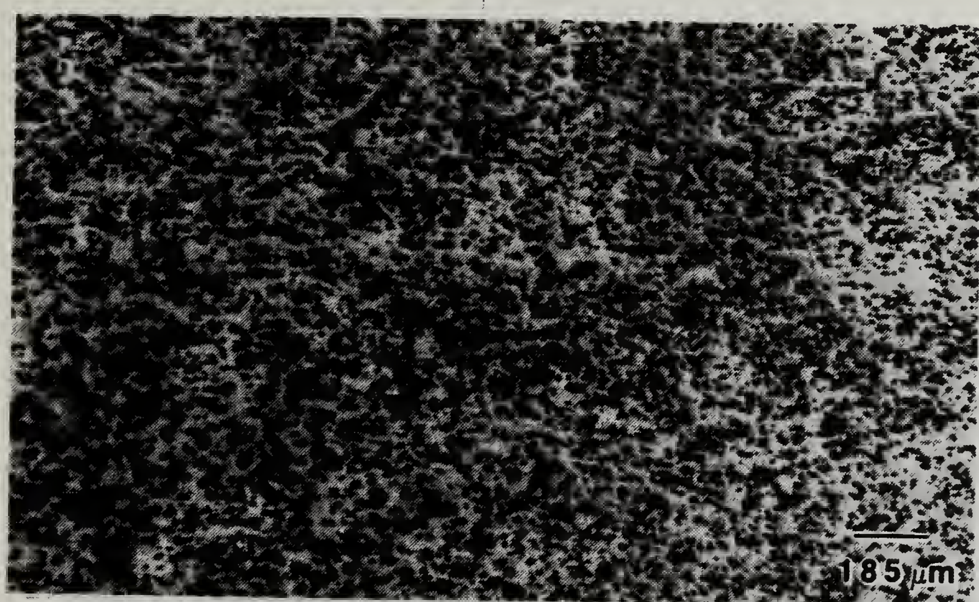

Figure 9. Sample A after rolling pass six, 10 vol. pct. Alumina (54X).

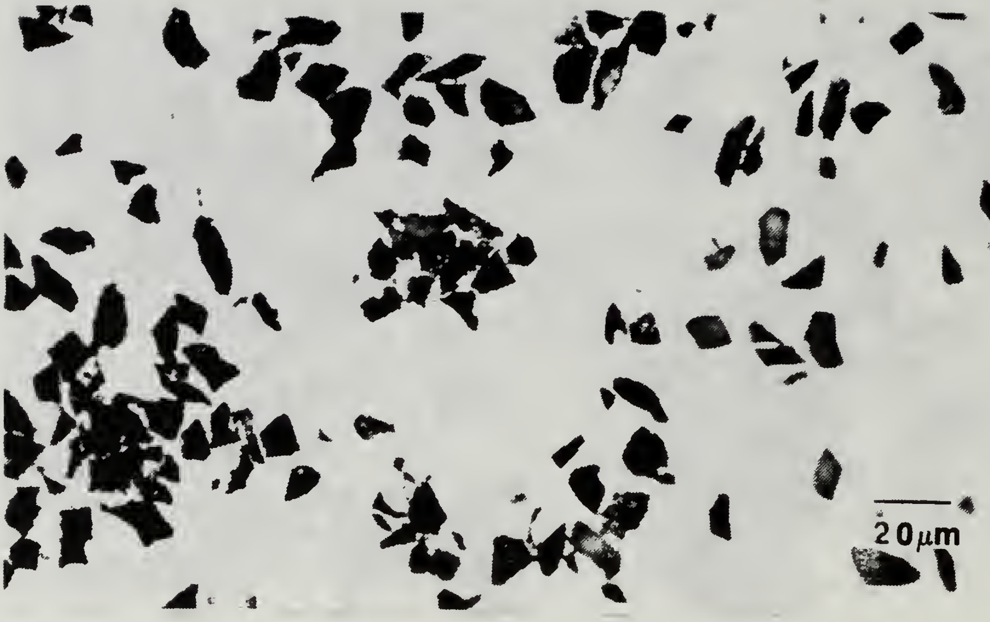

Figure 10. Sample C after rolling pass three, 15 vol. pct. Alumina (540X).

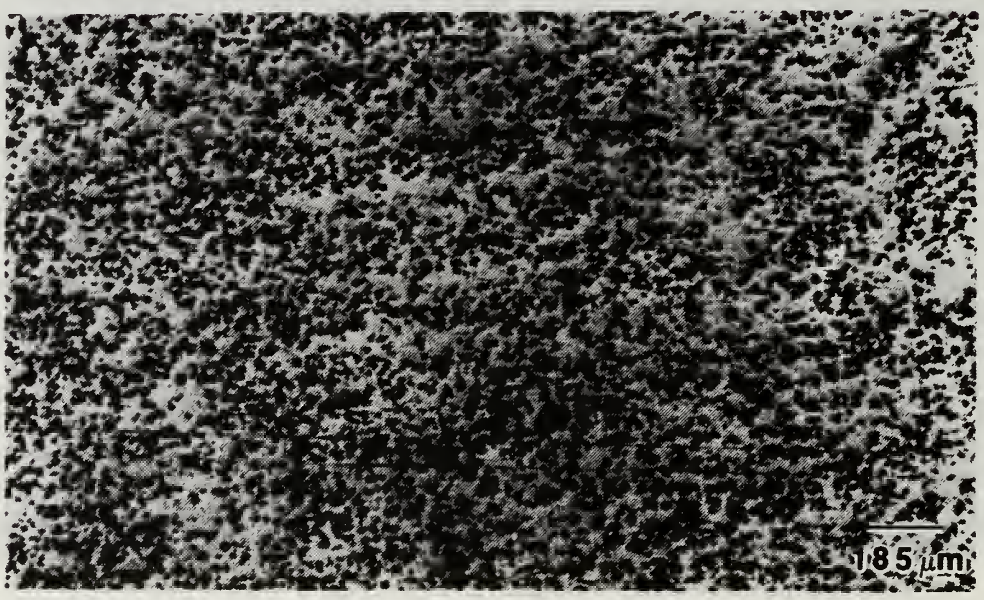

Figure 11. Sample A after rolling pass nine, 10 vol. pct. Alumina (54X).

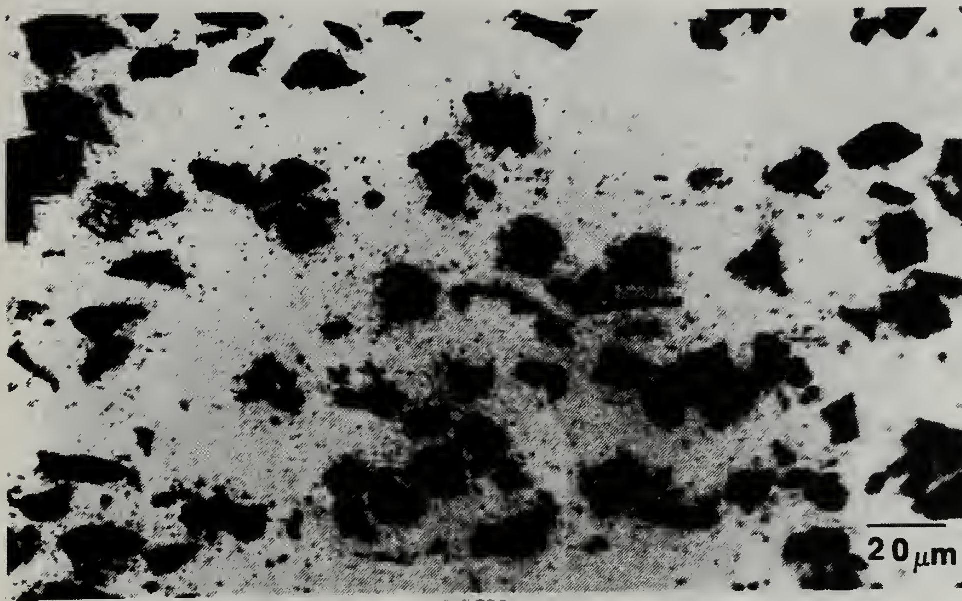

Figure 12. Sample C after rolling pass six, 15 vol. pct. Alumina (540X).

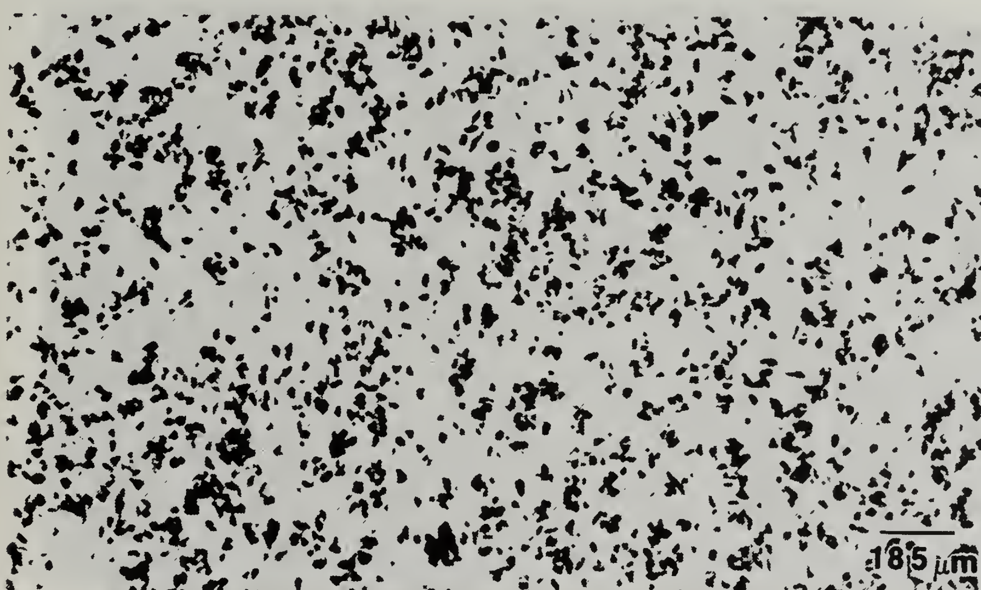

Figure 13. Sample C after rolling pass two, 15 vol. pct. Alumina (108X).

Figure 14. Sample C after rolling pass five, 15 vol. pct. Alumina (108X).

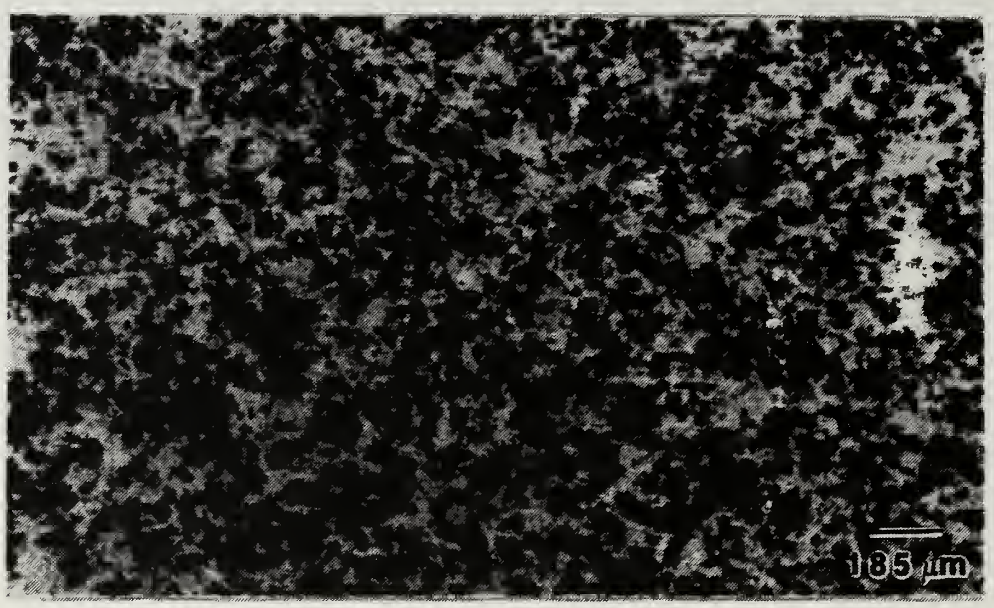

Figure 15. Sample C before rolling pass nine, 15 vol. pct. Alumina (54X).

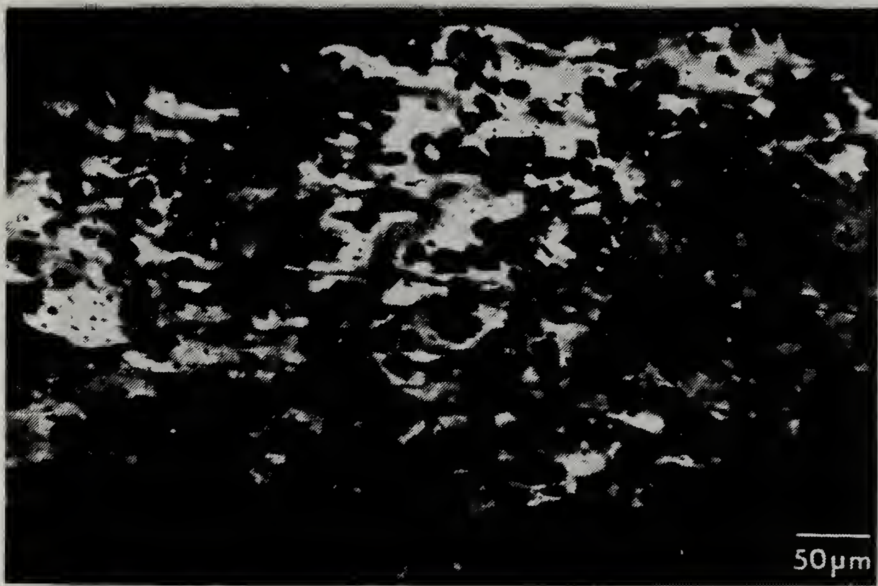

Figure 16. Sample C after rolling pass three, 15 vol. pct. Alumina (200X).

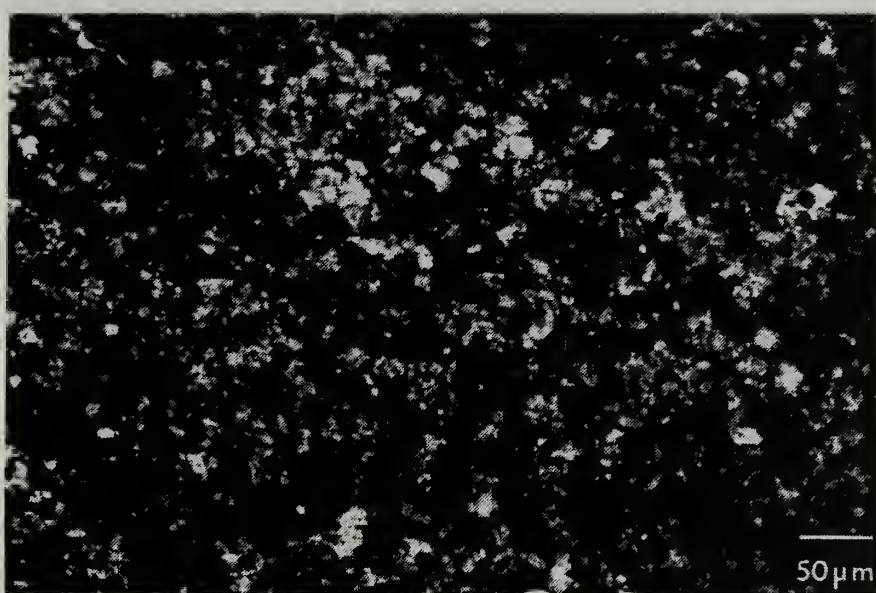

Figure 17. Sample C after rolling pass eight, 15 vol. pct. Alumina (200X).

Figure 18. Sample C after rolling pass three, 15 vol. pct. Alumina (200X).

mechanism of particle-stimulated nucleation can be seen in the TEM micrograph (Figure 23) which shows extensive dislocation entanglement at the vicinity of a particle. A high dislocation density can be observed next to a large Al_2O_3 particle. This would provide the driving force for the particle-stimulated recrystallization.

The extent of recrystallization is still greater after rolling pass nine of sample F (10 vol. pct. Al_2O_3) and G 15 vol. pct.Al_2O_3) as seen in Figure 19 and Figure 20, respectively. Both of these ha ne hour of annealing between rolling passes. Comparing among Figure 19, Figure 20, and Figure 17, reveals that structure is very similar in the 10 vol. pct. and 15 vol. pct. cases.

The TEM micrograph of sample C, Figure 21, shows a fine particle pinning the grain boundary. In the matrix region the dislocation density is relatively very low. It is similar to a fully recovered structure. The TEM micrograph of sample C in Figure 22 shows the fully recovered matrix with fine precipitates also present. The only notable difference is the precipitation of Mg_2Si that appears to be coarser with the longer reheating interval, (one hour for F and G versus one-half hour for C). Thus, increasing the reheating interval for either the 10 or 15 vol. pct. of material does not alter significantly the extent of microst ture refinement, but just coarsens the precipitates of the Mg_2Si phase.

The structure uniformly recrystallizes with a grain size that corresponds to the interparticle spacing. It has been suggested that the recrystallized grain size can be predicted based on volume percent and particle size. From Figure 24 it can be seen that for a 10 μm particle diameter we would expect a grain size of approximately 20 μm for 10 vol. pct. composite and a smaller grain size of about 17 μm for the 15 vol. pct. case [Ref. 17]. It is interesting to note that our result compares well with this prediction. In Figure 19 and Figure 20, we see a smaller grain size for the higher volume percent. The higher the volume percent of the particles, the lower the interparticle spacing and the finer the resulting grain. The more homogeneous the particle distribution, the more uniform the grain size. Both of these factors, then, contribute to a fine, uniform microstructure. The matrix starts out with fairly large grains which are refined and recrystallized by the end of the TMP.

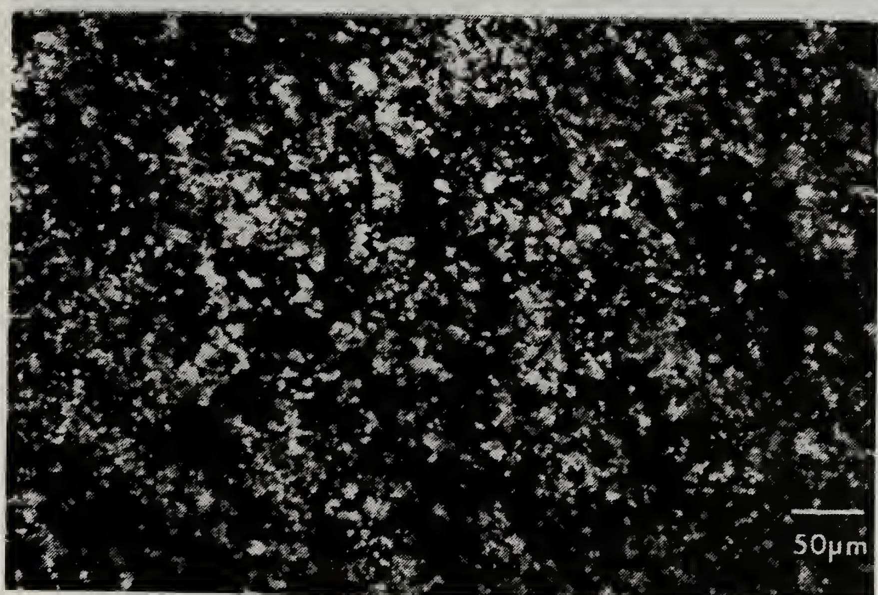

Figure 19. Sample F after rolling pass nine, 10 vol. pct. Alumina (200X).

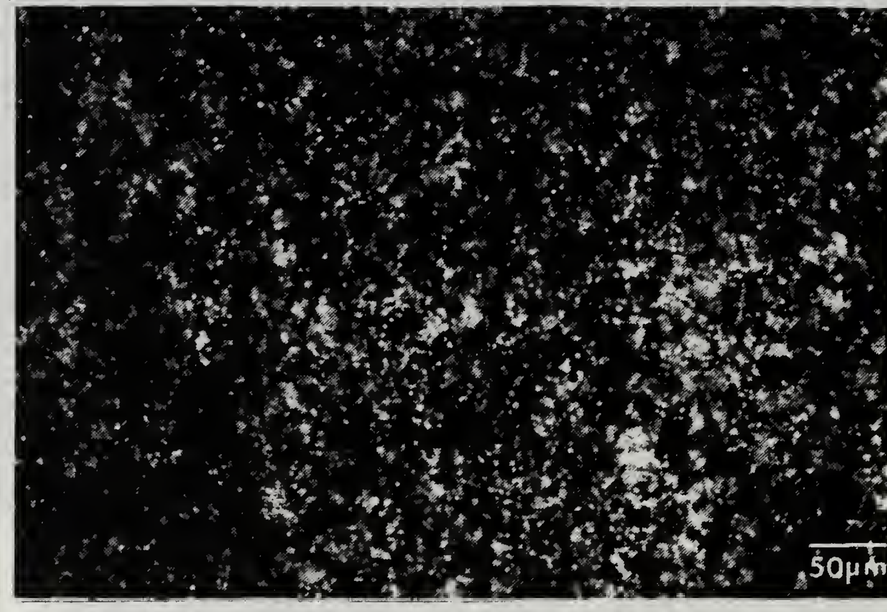

Figure 20. Sample G after rolling pass nine, 15 vol. pct. Alumina (200X).

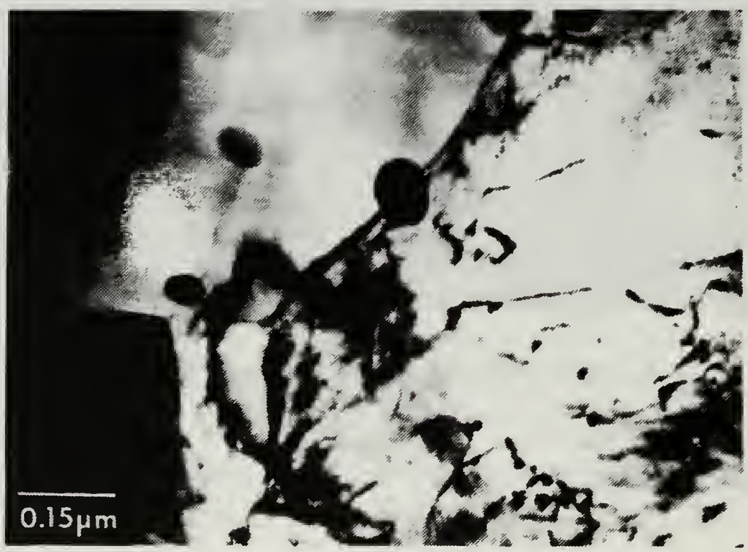

Figure 21. TEM micrograph, pinned grain boundary, 15 vol. pct. Alumina (80,000X)

Figure 22. TEM micrograph, matrix fully recovered, 15 vol. pct. Alumina (80,000X)

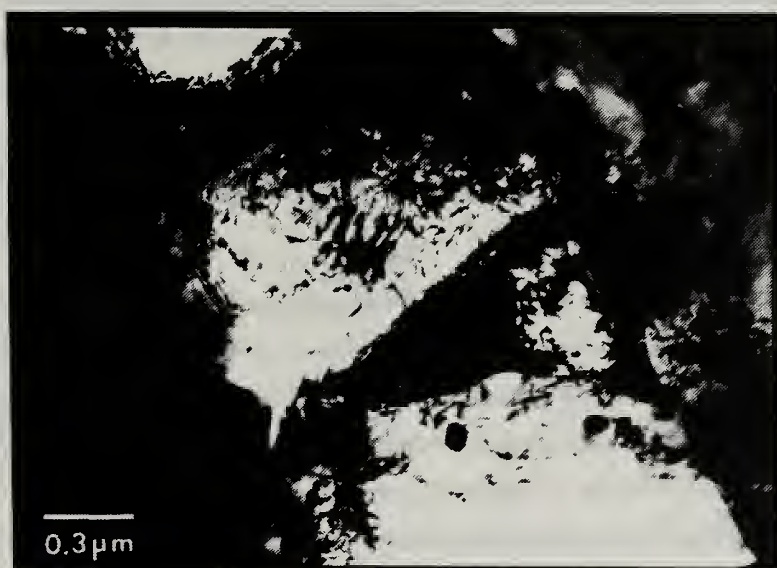

Figure 23. TEM micrograph showing high ρ, 15 vol. pct. Alumina (40,000X)

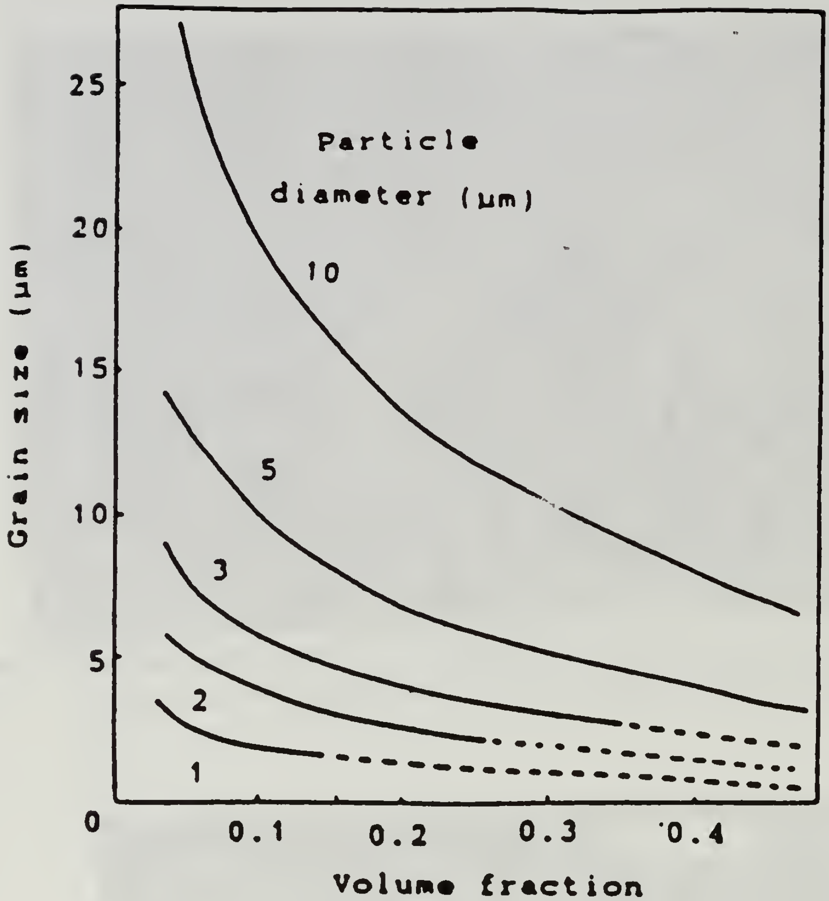

Figure 24. Grain size vs. volume percent and particle diameter ref. 1

2. Effects of Processing upon Mechanical Properties

a. The Temperature Dependence on Ductility

The as-cast material is extremely brittle. The as-extruded material has a ductility of about 10-15 percent elongation to fracture in the temperature interval of interest. A typical stress-strain curve from the current investigation is shown in Appendix B, and the ductility averaged between 20-60 percent elongation on this condition for the composite.

The ductility-temperature response does not vary significantly with the change in volume percentage of Al_2O_3. The ductility peaks at approximately 375°C for the 10 vol. pct. Al_2O_3 material (see Figure 26 in Appendix C). The corresponding temperature for the 15 vol. pct. sample was 425°C (see Figure 27). For samples F and G, which were annealed for one hour versus one-half hour for samples A and C (see

Figure 28 and Figure 29), the ductilities and peak temperature were comparable. A comparison of the previous work using one-half hour anneal and the current work done using one-hour of annealing is shown in Figure 30 and Figure 31 [ref. 13]. The ductility was found to be less than in the previous research. The previous data show a slightly higher tensile ductility when higher rolling temperatures are used. The ductility data for the current study are summarized in Appendix C. It is evident from these results that the TMP yields in an enhanced ductility when compared with the ductility of the as-extruded condition.

b. The Temperature Dependence of Ultimate Strength

The ambient temperature properties of this material is shown in Table 8 [Ref. 3]. It is noteworthy that both the ambient strength and ductility are improved by the processing.

The UTS decreases with increasing temperature as shown in Figure 32, Figure 33, Figure 34, and Figure 35 in Appendix D. As with the ductility, the ultimate strength (UTS) does not change significantly with the volume percentage of Al_2O_3. Comparing to data from previous work, different annealing time does not effect the UTS at higher test temperatures [Ref. 13]. Previous data showed an increase in strength at higher rolling temperatures (see Figure 36 and Figure 37). At lower rolling temperatures the specimens proved to be weaker at the lower tensile test temperatures.

Table 8. MECHANICAL PROPERTIES FOLLOWING AGING TO PEAK STRENGTH

Material Condition	Yield Strength (MPa)	Ultimate Tensile Strength (MPa)	Percent Elongation (%)
6061-T6 Unreinforced	276	310	12
Extruded	328	350	5.6
350°C Rolled	375	374	7.0

There are two general observations on the mechanical data:

1. Reduced pass temperature yields a material weaker at low test temperatures but without any enhancement in ductility.
2. Decreasing the anneal time between rolling passes increases the strength, and significantly enhances the ductility. Thirty minutes appears to be the optimum time.

C. SUMMARY

This investigation was a study of the effects of TMP on the evolution of the microstructure in an aluminum MMC containing either 10 or 15 vol. pct. Al_2O_3. The as-cast material is extremely brittle due to the non-homogeneous particle distribution in the matrix. When extruded at a 17 to 1 ratio, the particle distribution improved which resulted in higher strengths and ductilites. Thermomechanical processing by isothermal rolling at 250°C and 350°C further improved the particle distribution.

This study has followed the development of the microstructure from the beginning to the end of a rolling sequence. The processing did homogenize the microstructure. The particle distribution was improved without any sign of particle fracture. The matrix was recrystallized by the TMP and the matrix grains were refined from 500 to 20 μm. The mechanical properties were greatly improved when compared to the as-cast or extruded material. A longer anneal time between rolling passes seems to indicate a coarser microstructure with more time for grain growth and the precipitation of the Mg_2Si phase. The mechanical properties were enhanced in the ambient and elevated temperature tests [Ref. 3]. The lower pass temperature yielded a material weaker at low test temperatures without any enhancement in ductility. Decreasing the anneal time between rolling passes slightly increases the strength and significantly enhanced the ductility.

V. RECOMMENDATIONS FOR FURTHER STUDY

1. Perform identical experimentation on a monolith 6061 and compare to the MMC results.
2. Use TMP 2 (with the increasing strain per pass) and examine the microstructure and mechanical data as compared to TMP 1.
3. Attempt TMP 2 at 350°C for both rolling and annealing until approximately the fifth rolling pass and then use only 250°C for the rest of the process. This should prevent the alligator cracks early in the processing.
4. Increase the width to thickness ratio and decrease the length to width ratio to 3.0 to prevent "alligator" cracking. This will allow for the partially split material to be sectioned off and used for optical examination while still having ample material remaining to continue the TMP and machine a sufficient quantity of coupons.
5. Investigate the properties with an anneal time between rolling passes of approximately twenty minutes.
6. Investigate the properties of still higher volume fraction MMC.

APPENDIX A. PROGRAMS

A. DATA ACQUISITION PROGRAM

Due to the limitations of the Instron 6027 plotter, a program was written for the Hewlett Packard 3852A Data Acquisition Sysytem (HP) to acquire the load data from the Instron [Ref. 18]. This program was subsequently broken into two sub-programs with redundant sections removed and extra features added. This solved the problem of one program having inadequate memory to do all that was required. The first program called ACQR and the second is called REDUCE.

1. Users Guide

ACQR performs several functions. It will acquire the voltage signals from the Instron 6027 while plotting that load vs. time data simultaneously. The data can be graphed on the video screen or on the hard copy plotter. The data can then be stored on either the 3 1/2" floppy or hard disks.

Once the HP system is powered up, it will ask if you wish to use the floppy or hard disk drive to load the program. Choosing the hard drive will give the menu for the installed programs. Select item 7 for 'OTHER'. The next menu choice will be 'ACQR'. The program then asks if you wish to see the operating instructions which are summarized below. The instructions show:

1. Sample data
    a. Sample geometry and dimensions
    b. Identify sample
    c. Test temperature
    d. Cross head speed
    e. Load cell range
    f. Tension or compression test
    g. Plotting parameters
2. Running a Test
    a. Choose to view the data collection while in progress on the screen or plotter
    b. Start the test once the Instron is engaged
    c. Test complete
3. Save and Verify Data

a. Store data - the program looks at the number of data points and allocates a sector on the disk with the exact size of memory required. The program tells you the name of the last program saved as a reminder. You are filing the data in two stages. You are giving the name that the file will have and you allocate the amount of memory space needed to accomodate the file. The (empty) file is created in the correct size required. The second stage is the filing of the data into the empty file which had just been created in the name you have chosen.

b. Verify data - once filed, use 'RECALL OLD DATA' using the same name (the program will remind you what the last file was). If the recording was succesful you can replot the raw data or use the REDUCE program later.

The program will list the current files in the drive that is in use. It will notify the user if the disk in use is full and that another must be used to save the intended data. The data can be stored in the voltage signals or converted into load data and filed.

2. **Source Listing**

```
10     ! Program to acquire data by tha HP 3852A from the Instron 6027
15     ! Written 03-10-88 Tom Kellogg as INST 6027
20     ! Revised 09OCT90 by Paul Macri
25     ! Stored as ACQR
30     DIM Strain(5000),Strass(5000),Sample nr$[50],Area i(5000),Extens(5000)
35     ! note: Extens is used for inputting strain gage data
40     DIM X axis$[25]
41     File name$="NONE YET"
42 Startar:    !
43     PRINTER IS 1
45     KEY LABELS OFF
46     CLEAR SCREEN
47     PRINT "  "
48     PRINT " "
50     PRINT "                Do you want operating instructions?"
51     GOSUB Yes no
52     IF Answer$="N" THEN GOTO Init sec
53     OFF KEY
54     ON KEY 1 LABEL " Sample  Data    " GOTO Page 1
55     ON KEY 2 LABEL "Running  a Test " GOTO Paga 2
56     ON KEY 3 LABEL " Verify   Data " GOTO Page 3
57     ON KEY 4 LABEL "               " GOTO Ms spin
58     ON KEY 5 LABEL "               " GOTO Ms spin
59     ON KEY 6 LABEL "CONTINUE       " GOTO Init sec
60     ON KEY 7 LABEL " QUIT" GOTO Stopper
61     ON KEY 8 LABEL " MAIN    MENU " GOTO Main menu
62     KEY LABELS ON
63 Ms spin: GOTO Ms spin
64 Page 1: !
65          CLEAR SCREEN
```

```
66  PRINT "  OPERATING INSTRUCTIONS FOR OATA ACQUISITION"
67  PRINT " "
68  PRINT "I. Chanoe Current Set-uo                                          "
69  PRINT "   1. <NEED SAMPLE DIMENSIONS>                                     "
70  PRINT "       - samole geometry and dimensions        <RECT> & tyoe numbers <
RETURN>"
71  PRINT "   2. <IDENTIFY SAMPLE> - describe samole                       "
72  PRINT "   3. <CHANGE SET-UP>                                         "
73  PRINT "      A. <SAMPLE PARAMETERS>"
74  PRINT "          - <CHANGE TEMP>                                  tyoe heater tem
p"
75  PRINT "      B. <TEST PARAMETERS>"
76  PRINT "          - <CHANGE CROSS HEAD SPEED>"
77  PRINT "          - <CHANGE LC   CELL RANGE>"
78  PRINT "          - <TENSION/C    RESSION>"
79  PRINT "      C. <PLOTTING PA    ETERS>"
80  PRINT "          - X,Y axes labels; X,Y minimum and maximum values"
81  PRINT "   4. <SHOW SET-UP>  -  chanoe mistakes if any        "
82  PRINT "   5. <SET-UP OK> "
83  PRINT "                             "
84  PRINT " SEE 'Runnino a test' FOR THE INFORMATION NEEDED NEXT"
85  GOTO Ms soin
86 Paoe 2: !
87         CLEAR SCREEN
89  PRINT "  HOW TO START A TEST RUN"
90  PRINT " "
91  PRINT "II. <RUN>                                       "
92  PRINT "       - use olotter?                                   <YES>"
93  PRINT "       - load oaoer                                    <RETURN>"
94  PRINT "       - choose oen                                   draws axes"
96  PRINT " ensure INSTRON orinter is 'ONLINE' or there's NO OATA COMING"
97  PRINT " when INSTRON started and ready to acouire data        <RETURN>"
98  PRINT " when INSTRON finished and test comolete         <TEST COMPLETE>"
99  PRINT "   1. <MAIN MENU>                                  "
100 PRINT "   2. <STORE DATA>                                  "
101 PRINT "       - Do you want to store data to the flooov disk?     <YES>"
102 PRINT "       - file to be used?                          oive it a name"
103 PRINT "       - create a new file?                              <YES>"
104 PRINT "       - Do you want to store data?                      <YES>"
105 PRINT "                             "
106 PRINT "                             "
107 PRINT "                             "
108 PRINT " SEE 'Verify data' FOR THE INFORMATION NEEDED NEXT"
109 GOTO Ms soin
110 Paoe 3:!
111        CLEAR SCREEN
112 PRINT "  HOW TO VERIFY THE DATA WAS STORED ON THE FLOPPY DISK"
113 PRINT " "
114 PRINT "III. <RECALL OLD DATA>                                        "
115 PRINT "       - recall data from flooov?                        <YES>"
116 PRINT "       - file last used was:        "
```

```
117 PRINT "        - file to be used?                                    same name as abo
ve"
118 PRINT "        - Do you want to use plotter?                              <NO>"
119 PRINT "        - <MAIN MENU>"
120 PRINT "        - <SHOW SET-UP>                                          verify"
121 PRINT "        - <PLOT DATA>"
122 PRINT "        - <CHANGE MAIN AXES>                                  if needed"
123 PRINT "        - create a new file?                                       <YES>"
124 PRINT "        - Do you want to use plotter?                              <YES>"
125 PRINT "        - <CONTINUE PLOT>     "
126 PRINT "        - <PRINT DATA>                                  gives hard copy of set
-up"
127 PRINT "                                 "
128 PRINT "                                 "
129 PRINT " END OF INSTRUCTIONS          PRESS <CONTINUE>"
130 GOTO Ms spin
131 Init sec:  !
132   Str_rate=1.07 !mm/min
133   Gauge=12.7  !gauge length in mm
134   T start=0
135   T end=1000
136   T total=1000
137   Load min=0
138   Load max=2
139   Fs load cell=20
140   Test temp=300
141   X axis$="Time, minutes"
142   Y_axis$="Load, kN"
143   Te co=1 !TENSION ONLY TEST
144   Extensometer$="Off"
145   Ex convert=1
146   Ex inter=0
147   Exp con=1
148   Exp int=0
149   Explot0=0
150   Explotmax=20
151   Wide=0
152   Thick=0
153   GOSUB Show set up
154 Main_menu:  !
156   BEEP 2000,.1
157   OFF KEY
158   ON KEY 1 LABEL "Change  Set-up" GOTO Set up menu
159   ON KEY 2 LABEL "Show    Set-up" GOTO Show_set_up_q
160   ON KEY 3 LABEL " QUIT" GOTO Stopper
161   ON KEY 4 LABEL " QUIT" GOTO Stopper
162   ON KEY 5 LABEL "Store   Data" GOTO Store data
163   ON KEY 6 LABEL "Plot    Data" GOTO Plot_data
164   ON KEY 7 LABEL "Recall  Old Data" GOTO Recall data
165   ON KEY 8 LABEL "RUN" GOTO Set_up_ok
166   IF (Y axis$="Load, kN" OR Y_axis$="Stress, MPa") AND Fs_load cell=0 THEN
```

```
167      ON KEY 7 LABEL "NEED    LOADCELL" GOTO Load cell
168      ON KEY 8 LABEL "DATA    NEEDED" GOTO Main_menu
169      BEEP 2000,.1
170      BEEP 2500,.1
171    END IF
172    IF (Sample_area=0 OR Gauge=0) THEN
173      ON KEY 3 LABEL "NEED SA.DIMEN." GOTO S_area_1
174      ON KEY 8 LABEL "DATA    NEEDED" GOTO Main_menu
175      BEEP 2000,.1
176      BEEP 2500,.1
177    END IF
178    IF Sample_nr$="" THEN
179      ON KEY 4 LABEL "IDENTIFYSAMPLE"   TO Sample_id_m
180      ON KEY 8 LABEL "DATA    NEEDED"   TO Main menu
181      BEEP 2000,.1
182      BEEP 2500,.1
183    END IF
184    KEY LABELS ON
185 Main_menu_idle:GOTO Main_menu_idle
186 Sample_id_s:  !
187    ON KEY 1 LABEL "IdentifySample" GOTO Sample_id_s_2
188    ON KEY 2 LABEL "IdentifySample" GOTO Sample_id_s_2
189    ON KEY 3 LABEL "Change  Temp" GOTO Chg_test_temp
190    ON KEY 4 LABEL "Change  Temp" GOTO Chg_test_temp
191    FOR Q=5 TO 8
192      ON KEY Q LABEL "Change  Dimen's" GOTO S_area_2
193    NEXT Q
194 Sample_id_spin:GOTO Sample_id_spin
195 Chg_test_temp: !
196    Var=Test_temp
197    GOSUB Var_change
198    Test_temp=Var
199    GOTO Set_up_menu
200 Sample_id_s_2:  !
201    GOSUB Sample_id
202    GOTO Set_up_menu
203 Sample_id_m:  !
204    GOSUB Sample_id
205    GOTO Main_menu
206 Sample_id:  !
207    KEY LABELS OFF
208    INPUT "Identify sample 50 characters max",Sample_nr$
209    RETURN
210 S_area_1:  !
211    GOSUB S_area
212    GOTO Main_menu
213 S_area_2:  !
214    GOSUB S_area
215    GOTO Set_up_menu
216 Show_set_up_g:  !
217    GOSUB Show_set_up
```

```
218   GOTO Main_menu
219 Recall_data:!
220   GOSUB Re_data
221   GOTO Plot_data
222 Re_data:!
223   GOSUB Which_msu
224   ON ERROR GOTO Input_err
225   INPUT "File to be used? Don't type suffix X,Y,Z or Q.",File_name$
226   Xfile$=File_name$&"B"
227   Yfile$=File_name$&"C"
228   Zfile$=File_name$&"Z"
229   Qfile$=File_name$&"Q"
230   ASSIGN @Path1 TO Xfile$
231   ASSIGN @Path2 TO Yfile$
232   ASSIGN @Path3 TO Zfile$
233   ASSIGN @Path4 TO Qfile$
234   N_points=5000!THIS IS TO RESET FROM LAST N_points SO ALL DATA IS PLOTTED
236 ! ON END @Path3 GOTO Plot_data
237   OFF ERROR
238   ON ERROR GOTO 240
239   ENTER @Path1;Strain(*)
240   OFF ERROR
241   ON ERROR GOTO 243
242   ENTER @Path2;Stress(*)
243   OFF ERROR
244   ON ERROR GOTO 248
245   E_c=Ex_convert
246   E_i=Ex_inter
247   ENTER @Path3;Sample_nr$,X_axis$,Y_axis$,Dia,Wide,Thick,Gauge,T_start,T_end
,Load_min,Load_max,Fs_load_cell,Te_co,Str_rate,Extensometer$,E_c,E_i,Test_temp
248   OFF ERROR
249   ON ERROR GOTO 252
250   ENTER @Path4;Extens(*)
251   OFF ERROR
252   ASSIGN @Path4 TO *
253   ASSIGN @Path1 TO *
254   ASSIGN @Path2 TO *
255   ASSIGN @Path3 TO *
256   RETURN
257 Input_err:  !
258   PRINTER IS 1
259   IF ERRN=56 THEN
260     PRINTER IS 701
261     CAT
262     FOR Q=1 TO 5
263       PRINT
264     NEXT Q
265     PRINTER IS 1
266   END IF
267   PRINT USING "@,#"
```

```
268   BEEP
269   PRINT ERRM$
270   GOTO Recall_data
271 Store_data:!
272   GOSUB Which_msu
273   ON ERROR GOTO Store_err
274   PRINT "Name of last file is:    ",File_name$
275   INPUT "File to be used? Don't type suffix B,C,orZ.",File_name$
276   Xfile$=File_name$&"B"
277   Yfile$=File_name$&"C"
278   Zfile$=File_name$&"Z"
279   Qfile$=File_name$&"Q"
280   ASSIGN @Path1 TO Xfile$
281   ASSIGN @Path2 TO Yfile$
282   ASSIGN @Path3 TO Zfile$
283   ASSIGN @Path4 TO Qfile$
284   ON END @Path4 GOTO Main_menu
285   OFF ERROR
286   ON ERROR GOTO 288
287   OUTPUT @Path1;Strain(*)
288   OFF ERROR
289   ON ERROR GOTO 291
290   OUTPUT @Path2;Stress(*)
291   OFF ERROR
292   ON ERROR GOTO 296
293   E_c=Ex_convert
294   E_i=Ex_inter
295   OUTPUT @Path3;Sample_nr$,X_axis$,Y_axis$,Dia,Wide,Thick,Gauge,T_start,T_en
d,Load_min,Load_max,Fs_load_cell,Te_co,Str_rate,Extensometer$,E_c,E_i,Test_temp
296   OFF ERROR
297   ON ERROR GOTO 300
298   OUTPUT @Path4;Extens(*)
299   OFF ERROR
300   ASSIGN @Path4 TO *
301   ASSIGN @Path1 TO *
302   ASSIGN @Path2 TO *
303   ASSIGN @Path3 TO *
304   MASS STORAGE IS ":CS80,700,1"
305   GOTO Main_menu
306 Store_err:  !
307   PRINTER IS 1
308   IF ERRN=56 THEN
309     OFF ERROR
310     PRINT "File not found. Below is a list of current files."
311     CAT
312     FOR Q=1 TO 5
313       PRINT
314     NEXT Q
315     PRINT "Would you like to create a new file?   <Y> if this is new data"
316     GOSUB Yes_no
317     IF Answer$="Y" THEN
```

```
318       PRINT "Insert data disk"
319       BEEP
320 New_file:       !
321       ON ERROR GOTO Disk_full
322       PRINT "Creating new files....................."
323       CREATE BDAT File_name$&"B",8,N_points
324       CREATE BDAT File_name$&"C",8,N_points
325       CREATE BDAT File_name$&"Z",1,100!ITS STILL LESS THAN 1000
326       CREATE BDAT File_name$&"Q",1,N_points
327       OFF ERROR !N_points is the # of data points acquired
328     ELSE
329       GOTO Store_data
330     END IF
331   ELSE
332     PRINT ERRM$
333     OFF ERROR
334     PRINT "Do you want to try again?"
335     GOSUB Yes_no
336     IF Answer$="Y" THEN Store_data
337     GOTO Main_menu
338   END IF
339   PRINT USING "@,#"
340   BEEP
341   GOTO Store_data
342 Disk_full:  !
343   OFF ERROR
344   PRINT "This disk is full. Do you want to replace it with a new disk?"
345   GOSUB Yes_no
346   IF Answer$="N" THEN Store_data
347   GOTO New_file
348 Print_data:  !
349   PRINTER IS 701
350   GOSUB Show_set_up_2
351   PRINTER IS 1
352   GOTO Main_menu
353 Plot_data:  !
354   GOSUB Plot_set_up
355   L_type=0
356 Next_curve:  !
357   L_type=L_type+1
358   LINE TYPE L_type
359   OFF KEY
360   ON KEY 1 LABEL "ContinuePlot" GOTO Plot_data_2
361   ON KEY 2 LABEL "CHANGE  MAINAXES" GOTO Plot_axes
362   ON KEY 3 LABEL "                " GOTO Plot_data_idle
363   ON KEY 4 LABEL "NEW     PLOT" GOTO Main_menu
364   ON KEY 5 LABEL "Main    Menu" GOTO Main_menu
365   ON KEY 6 LABEL "Print   Data" GOTO Print_data
366   IF Extensometer$="ON" THEN
367     ON KEY 7 LABEL "LOAD-   STRAIN" GOTO Plot_data_3
368   ELSE
```

```
369     ON KEY 7 LABEL "                " GOTO Plot_data_idle
370   END IF
371   ON KEY 8 LABEL "LOAD-    TIME" GOTO Plot_data_2
372   KEY LABELS ON
373 Plot_data_idle:GOTO Plot_data_idle
374 Plot_axes:  !
375   GOSUB Axes_u
376   GOSUB Start_t
377   GOSUB Plot_set_up
378   GOTO Plot_data_2
379 Sub_axes:  !
380   GOSUB Ex_plt_cnv
381   GOSUB Plot_set_up
382   GOTO Plot_data_2
383 Plot_data_3:  !
384   GOSUB Pen_select
385   KEY LABELS OFF
386   IF Answer$="Y" THEN GOSUB Pen_select
387   FOR I=1 TO 5000
388     Explot=Extens(I)*Exp_con+Exp_int
389     IF I=1 OR Explot=T_start THEN MOVE Explot,Stress(I)
390     IF Explot<T_start OR Explot>T_end THEN End_plot_3
391     PLOT Explot,Stress(I)
392 End_plot_3:  !
393   NEXT I
394   IF Answer$="Y" THEN PEN 0
395   GOTO Next_curve
396 Re_data_1:  !
397   GOSUB Re_data
398 Plot_data_2:  !
399   IF Which_pltr$="Plotter" THEN GOSUB Pen_select
400   KEY LABELS OFF
401   FOR I=1 TO 5000
402   IF I=N_points THEN GOTO Next_curve
403     IF I=1 OR Strain(I)=T_start THEN MOVE Strain(I),Stress(I)
404     IF Strain(I)<T_start THEN End_curve
405     IF Te_co=1 AND (Stress(I)>Load_max OR Stress(I)<Load_min) THEN GOTO End_
curve
406     IF Te_co=3 AND (Stress(I)<Load_max OR Stress(I)>Load_min) THEN GOTO End_
curve
407     IF Strain(I)>T_end THEN
408       I=5000
409       GOTO End_curve
410     END IF
411   IF I>N_points AND Strain(I)=0 THEN
412   GOTO Next_curve
413   END IF
415     PLOT Strain(I),Stress(I)
416 End_curve:     !
417   NEXT I
418   IF Answer$="Y" THEN PEN 0
419   GOTO Next_curve
420 Show_set_up_1:  !
```

```
421   GOSUB Show_set_up
422   GOTO Main_menu_idle
423 Stopper: !
424   PRINTER IS 1
425   KEY LABELS OFF
426   PRINT "Do you want to reduce data or use another program?"
427   GOSUB Yes_no
428   IF Answer$="Y" THEN LOAD "MSLABS"
429   STOP
430 Load_cell:  !
431   KEY LABELS OFF
432   INPUT "What is the full-scale load value in kN?",Fs_load_cell
433   GOTO Main_menu
434 S_area:  !
435   OFF KEY
436   FOR Q=1 TO 4
437     ON KEY Q LABEL "round   sample" GOTO Round
438     ON KEY Q+4 LABEL "rect.   sample" GOTO Rect
439   NEXT Q
440   KEY LABELS ON
441 S_area_idle:GOTO S_area_idle
442 Round:!
443   KEY LABELS OFF
444   INPUT "Sample diameter, mm?",Dia
445   Sample_area=(PI/4)*(Dia^2)
446   GOTO G_length
447 Rect:  !
448   KEY LABELS OFF
449   INPUT "Sample width, mm?",Wide
450   INPUT "Sample thickness, mm?",Thick
451   Sample_area=Wide*Thick
452 G_length: !
453   PRINT "Default gauge length is ",Gauge;" mm. Hit <RETURN> to accept"
454   INPUT "Gauge length, mm?",Gauge
455   RETURN
456 Show_set_up:!
457   PRINTER IS 1
458 Show_set_up_2:  !
459   PRINT USING "@,#"
460   PRINT "Current set up is as follows:"
461   PRINT "   Sample Parameters:"
462   IF Sample_nr$="" THEN
463     PRINT "      Sample unnamed"
464   ELSE
465     PRINT "      Sample: ";Sample_nr$
466   END IF
467   IF Gauge<>0 THEN
468     PRINT "      Gauge length is ";Gauge;" mm"
469   ELSE
470     PRINT "      No gauge length specified"
471   END IF
472   IF Dia<>0 THEN Sample_area=(PI/4)*(Dia^2)
```

```
473   IF Thick<>0 AND Wide<>0 THEN Sample_area=Wide*Thick
474   IF Sample_area<>0 THEN
475     IF Dia<>0 THEN
476       PRINT "     Using round sample with a diameter of ";Dia;" mm"
477     ELSE
478       PRINT "     Using flat sample ";Wide;" mm wide X ";Thick;"mm thick"
479     END IF
480     PRINT "     Sample area is ";Sample_area;" mm^2"
481   ELSE
482     PRINT "     Sample dimensions are incomplete"
483   END IF
484   PRINT
485   PRINT "   Testing Parameters:"
486   PRINT "     Crosshead speed";Str_rate;" mm/min"
487   PRINT "     Full-scale range of load cell is set for ";Fs_load_cell;"kN"
488   PRINT "     Hold time at finish ";Hold_time;" min"
489   IF Te_co=1 THEN PRINT "     Tension only test"
490   IF Te_co=2 THEN PRINT "     Tension/compression test"
491   IF Te_co=3 THEN PRINT "     Compression only test"
492   PRINT "      Extensometer/Strain Gage is ";Extensometer$
493   IF Extensometer$="On" THEN
494     PRINT "     Extensometer/Strain gage conversion factor is ";Ex_convert
495     PRINT "     Extensometer/Strain gage intercept is ";Ex_inter
496     PRINT "     Strain shown will be from ";Explot0;" to ";Explotmax
497   END IF
498   PRINT "     Test temperature is ";Test_temp;" deg C or ";Test_temp+273.16;
" K"
499   PRINT
500   PRINT "   Plotting Parameters:"
501   IF X_axis$="Time, minutes" THEN PRINT "     Start time ";T_start;" min   F
inish time ";T_end;" min"
502   IF X_axis$="Time, seconds" THEN PRINT "     Start time ";T_start;" sec   F
inish time ";T_end;" sec"
503   IF X_axis$="Elongation, mm" THEN PRINT "     Starting Elongation ",T_start
;" mm    Finish Elongation ";T_end;" mm"
504   IF X_axis$="Elongation, Percent" THEN PRINT "     Starting Elongation ",T_
start;" %    Finish Elongation ";T_end;" %"
505   IF X_axis$="Strain" THEN PRINT "     Starting strain ",T_star    Finish st
rain ";T_end
506   IF Y_axis$="Volts DC" THEN PRINT "     Y-axis minimum is ";L   :_min;" volt
s  and Y-axis maximum is ";Load_max;" volts"
507   IF Y_axis$="Millivolts DC" THEN PRINT "     Y-axis minimum is ";Load_min;"
 millivolts  and Y-axis maximum is ";Load_max;" millivolts"
508   IF Y_axis$="Load, kN" THEN PRINT "     Load ranges from ",Load_min;" kN to
 ";Load_max;" kN  (neg value means compression)"
509   IF Y_axis$="Stress, MPa" THEN
510     PRINT "     Stress ranges from ",Load_min;" MPa to ";Load_max;" MPa"
511     PRINT "     (neg value means compression)"
512   END IF
513   RETURN
514 Set_up_menu:  !
```

```
515   BEEP 2000,.2
516   BEEP 2100,.2
517   OFF KEY
518   GOSUB Show_set_up
519   ON KEY 1 LABEL "Sample  Params" GOTO Sample_id_s
520   ON KEY 2 LABEL "Sample  Params" GOTO Sample_id_s
521   ON KEY 3 LABEL "Test    Params" GOTO Test_params
522   ON KEY 4 LABEL "Test    Params" GOTO Test_params
523   ON KEY 5 LABEL "PlottingParams" GOTO Axes_units
524   ON KEY 6 LABEL "PlottingParams" GOTO Axes_units
525   ON KEY 7 LABEL "" GOTO Set_up_idle
526   ON KEY 8 LABEL "SETUP   OK" GOTO Main_menu
527   IF Sample_nr$="" THEN ON KEY 8 LABEL "IDENTIFYSAMPLE" GOTO Sample_id_s
528   IF (Y_axis$="Load, kN" OR Y_axis$="Stress, MPa") AND Fs_load_cell=0 THEN
529     ON KEY 8 LABEL "NEED    LOADCELL" GOTO Load_cell
530     BEEP 2000,.1
531   END IF
532   IF (Y_axis$="Stress, MPa" AND Sample_area=0) OR (X_axis$="Elongation, %" O
R X_axis$="Strain" AND Gauge=0) THEN
533     ON KEY 8 LABEL "SAMPLE  DIMEN." GOTO S_area_2
534   END IF
535   IF (X_axis$="Elongation, mm" OR X_axis$="Elongation, %" OR X_axis$="Strain
") AND Str_rate=0 THEN
536     ON KEY 7 LABEL "X-head  Speed" GOTO Rates
537     ON KEY 8 LABEL "" GOTO Rates
538   END IF
539   KEY LABELS ON
540 Set_up_idle:GOTO Set_up_idle
541 Test_params:  !
542   ON KEY 1 LABEL "Change  X-head V" GOTO Rates
543   ON KEY 2 LABEL "Change  Load Cell" GOTO Load_cell
544   ON KEY 3 LABEL "Tension/Compression" GOTO Ten_com
545   ON KEY 4 LABEL "Hold    Time" GOTO Holds
546   ON KEY 5 LABEL "Extens. Toggle" GOTO Extoggle_1
547   FOR Q=6 TO 8
548     ON KEY Q LABEL "" GOTO Test_par_spin
549   NEXT Q
550 Test_par_spin:GOTO Test_par_spin
551 Extoggle_1:  !
552   GOSUB Ex_toggle
553   GOSUB Ex_cnv
554   GOSUB Ex_plt_cnv
555   GOTO Set_up_menu
556 G_l_set_up:  !
557   Var=Gauge
558   PRINT "Changing gauge length"
559   GOSUB Var_change
560   Gauge=Var
561   GOTO Set_up_menu
562 Start_t:  !
563   Var=T_start
```

```
564   PRINT "Changing minimum x-axis value:"
565   GOSUB Var_change
566   T_start=Var
567   Var=T_end
568   PRINT "Changing maximum x-axis value:"
569   GOSUB Var_change
570   T_end=Var
571   T_ran=T_end-T_start
572 Load_vals:  !
573   Var=Load_min
574   PRINT "Changing minimum y-axis value:"
575   GOSUB Var_change
576   Load_min=Var
577   Var=Load_max
578   PRINT "Changing maximum y-axis value:"
579   GOSUB Var_change
580   Load_max=Var
581   Load_ran=Load_max-Load_min
582   RETURN
583 Axes_units:  !
584   GOSUB Axes_u
585   GOSUB Start_t
586   GOTO Set_up_menu
587 Axes_u:  !
588   KEY LABELS OFF
589   OFF KEY
590   PRINT "Select label for X-axis. Default is time in minutes"
591   ON KEY 1 LABEL "Time    Minutes" GOTO Time_min
592   ON KEY 2 LABEL "Time    Seconds" GOTO Time_sec
593   ON KEY 3 LABEL "Elong.  mm" GOTO Elong_mm
594   ON KEY 4 LABEL "Elong.  %" GOTO Elong_pct
595   ON KEY 5 LABEL "Strain" GOTO Strain_axis
596   FOR Q=6 TO 8
597     ON KEY Q LABEL "" GOTO Axes_idle
598   NEXT Q
599   KEY LABELS ON
600 Axes_idle:GOTO Axes_idle
601 Time_min:!
602   X_axis$="Time, minutes"
603   GOTO Set_up_y_axis
604 Time_sec:!
605   X_axis$="Time, seconds"
606   GOTO Set_up_y_axis
607 Elong_mm:!
608   X_axis$="Elongation, mm"
609   GOTO Set_up_y_axis
610 Elong_pct:!
611   X_axis$="Elongation, Percent"
612   GOTO Set_up_y_axis
613 Strain_axis:!
614   X_axis$="Strain"
```

```
615 Set_up_y_axis:!
616   OFF KEY
617   PRINT "Select label for Y-axis. Default is load"
618   ON KEY 3 LABEL "Volts   DC" GOTO Volts_y
619   ON KEY 4 LABEL "mV      DC" GOTO Mv_y
620   ON KEY 1 LABEL "Load, kN" GOTO Load_y
621   ON KEY 2 LABEL "Stress, MPa" GOTO Stress_y
622   FOR Q=5 TO 8
623     ON KEY Q LABEL "" GOTO Y_ax_idle
624   NEXT Q
625   KEY LABELS ON
626 Y_ax_idle:GOTO Y_ax_idle
627 Volts_y:!
628   Y_axis$="Volts DC"
629   RETURN
630 Mv_y:!
631   Y_axis$="Millivolts DC"
632   RETURN
633 Load_y:!
634   Y_axis$="Load, kN"
635   RETURN
636 Stress_y:!
637   Y_axis$="Stress, MPa"
638   RETURN
639 Rates:  !
640   Var=Str_rate
641   PRINT "Editing crosshead speed: give value in mm/min"
642   GOSUB Var_change
643   Str_rate=Var
644   GOTO Set_up_menu
645 Holds:  !
646   GOSUB Holds1
647   GOTO Set_up_menu
648 Holds1:  !
649   PRINT "Change hold time?"
650   GOSUB Yes_no
651   IF Answer$="Y" THEN
652     Var=Hold_time
653     GOSUB Var_change
654     Hold_time=Var
655   END IF
656   RETURN
657 Ex_toggle:  !
658   PRINT "Toggle extensometer?"
659   GOSUB Yes_no
660   IF Answer$="N" THEN 668
661   IF Extensometer$="Off" THEN
662     Extensometer$="On"
663   ELSE
664     Extensometer$="Off"
665   END IF
```

```
666   RETURN
667 Ex_cnv:  !
668   IF Extensometer$="On" THEN
669     PRINT "Change conversion factor?"
670     GOSUB Yes_no
671     IF Answer$="Y" THEN
672       Var=Ex_convert
673       GOSUB Var_change
674       Ex_convert=Var
675     END IF
676     PRINT "Change intercept?"
677     GOSUB Yes_no
678     IF Answer$="Y" THEN
679       Var=Ex_inter
680       GOSUB Var_change
681       Ex_inter=Var
682     END IF
683   END IF
684   RETURN
685 Ex_plt_cnv:  !
686   IF Extensometer$="On" THEN
687     PRINT "Change minimum strain plotted?"
688     GOSUB Yes_no
689     IF Answer$="Y" THEN
690       Var=Explot0
691       GOSUB Var_change
692       Explot0=Var
693     END IF
694     PRINT "Change maximum strain plotted?"
695     GOSUB Yes_no
696     IF Answer$="Y" THEN
697       Var=Explotmax
698       GOSUB Var_change
699       Explotmax=Var
700     END IF
701     Exp_con=(T_start-[illegible]nd)/[illegible]plot0-Explotmax)
702     Exp_int=T_start-E[illegible]ot0*E[illegible]_con
703   END IF
704   RETURN
705 Ten_com:  !
706   KEY LABELS OFF
707   PRINT "TENSION, TENSION/COMPRESSION OR COMPRESSION TEST?"
708   BEEP 2000,.1
709   OFF KEY
710   ON KEY 1 LABEL "TENSION" GOTO Ten_only
711   ON KEY 2 LABEL "TENSION" GOTO Ten_only
712   ON KEY 3 LABEL "" GOTO Ten_idle
713   ON KEY 4 LABEL "TENSION/COMPRESS" GOTO Ten_and_com
714   ON KEY 5 LABEL "TENSION/COMPRESS" GOTO Ten_and_com
715   ON KEY 6 LABEL "" GOTO Ten_idle
716   ON KEY 7 LABEL "COMPRESS" GOTO Com_only
```

```
717   ON KEY 8 LABEL "COMPRESS" GOTO Com_only
718   KEY LABELS ON
719 Ten_idle:GOTO Ten_idle
720 Ten_only:Te_co=1
721   GOTO Set_up_menu
722 Ten_and_com:Te_co=2
723   GOTO Set_up_menu
724 Com_only:Te_co=3
725   GOTO Set_up_menu
726 Var_change:!
727   INPUT "Type in desired value",Var
728   PRINTER IS 1
729   PRINT Var;"Is this OK?"
730   GOSUB Yes_no
731   IF Answer$="N" THEN Var_change
732   RETURN
763 Set_up_ok:!
764 Init_daq:!
765   KEY LABELS OFF
766   GOSUB Plot_set_up
767   OUTPUT 709;"CLR"
768   OUTPUT 709;"USE 000"
769   PRINTER IS 1
770 Re_test:  !
771 Acq_data:!
772   IF Which_pltr$="CRT" THEN
773     Penn$="Data"
774     GOSUB Pen_select
775   END IF
776   FOR Q=1 TO 4
777     ON KEY Q LABEL "TEST    COMPLETE" GOTO Test_done
778     ON KEY Q+4 LABEL "RE-STARTTEST" GOTO Re_test
779   NEXT Q
780   KEY LABELS ON
781   T_total=T_end-T_start
782   T_convert=1 !assumes x-axis is in seconds
783   IF X_axis$="Time, minutes" THEN T_convert=1/60
784   IF X_axis$="Elongation, mm" THEN T_convert=Str_rate/60
785   IF X_axis$="Elongation, %" THEN T_convert=(Str_rate/Gauge)*(100/60)
786   IF X_axis$="Strain" THEN T_convert=(Str_rate/60)/Gauge
787   L_convert=1 !assumes DCV is output
788   IF Y_axis$="Millivolts DC" THEN L_convert=1000
789   IF Y_axis$="Load, kN" THEN L_convert=Fs_load_cell/10
790   IF Y_axis$="Stress, MPa" THEN L_convert=(Fs_load_cell*100)/Sample_area
791   KEY LABELS OFF
792   INPUT "Hit <RETURN> when ready to proceed.",Which$
793   KEY LABELS ON
794   T_0=TIMEDATE   !Time is measured in seconds then converted to desired unit
795   LORG 5
```

```
796   FOR I=0 TO 5000
797     REPEAT
798       T_i=(TIMEDATE-T_0)*T_convert
799     UNTIL T_i>=(T_total/5000)*(I)
800     Strain(I)=T_i
801     OUTPUT 709;"CONFMEAS DCV,214"
802     ENTER 709;Stress(I)
803     Stress(I)=Stress(I)*L_convert
804     PLOT Strain(I),Stress(I)
805     IF Extensometer$="On" THEN
806       OUTPUT 709;"CONFMEAS DCV,215"
807       ENTER 709;Extens(I)
808       Extens(I)=Extens(I)*Ex_convert+Ex_inter!CONVERTS TO STRAIN VALUES
809       Explot=Exter     *Exp_con+Exp_int!CONVERTS STRAIN TO PLOTABLE VALUES
810       MOVE Explot      ss(I)
811       LABEL USING      '*"
812     END IF
813   NEXT I
814 Test_done:  !
815   N_points=I!THIS IS THE LAST DATA POINT ACQUIRED
816   OFF KEY !        AND THE PLOTTER DOESN'T GO NUTS
817   FOR Q=1 TO 4
818     ON KEY Q LABEL "            " GOTO Dumper!DUMP  PLOT???
819     ON KEY Q+4 LABEL "Main    Menu" GOTO Main_menu
820   NEXT Q
821 T_d_idle:GOTO T_d_idle
822 Pen_select:  !
823   ON KEY 1 LABEL "Pen 1" GOTO P1
824   ON KEY 2 LABEL "Pen 2" GOTO P2
825   ON KEY 3 LABEL "Pen 3" GOTO P3
826   ON KEY 4 LABEL "Pen 4" GOTO P4
827   ON KEY 5 LABEL "Pen 5" GOTO P5
828   ON KEY 6 LABEL "Pen 6" GOTO P6
829   ON KEY 7 LABEL "Drawing "&Penn$ GOTO Pen_select_idle
830   ON KEY 8 LABEL "Drawing "&Penn$ GOTO Pen_select_idle
831   KEY LABELS ON
832   BEEP 2000,.1
833 Pen_select_idle:GOTO Pen_select_idle
834 P1:PEN 1
835   GOTO Pen_return
836 P2:PEN 2
837   GOTO Pen_return
838 P3:PEN 3
839   GOTO Pen_return
840 P4:PEN 4
841   GOTO Pen_return
842 P5:PEN 5
843   GOTO Pen_return
844 P6:PEN 6
845 Pen_return: !
846   KEY LABELS OFF
```

```
847   RETURN
848 Dumper: !
849   KEY LABELS OFF
850   DUMP DEVICE IS 701
851   OUTPUT KBD;"N";
852   GOTO Main_menu
853 File_err:  !
854   PRINTER IS 1
855   PRINT USING "@,#"
856   BEEP 2000,.3
857   IF ERRN=78 OR ERRN=85 THEN
858     PRINT "WARNING you  are initializing this disc. All data will be erased.
"
859     INPUT "Hit <RETURN> to continue",Which$
860     INITIALIZE ":CS80,700,1"
861   END IF
862   PRINT "Error in file name selection",ERRN,ERRM$
863   GOTO Data_save
864 Plot_set_up:  !
865   PRINTER IS 1
866   OFF KEY
867   PRINT "Do you want to use the Plotter?"
868   GOSUB Yes_no
869   OUTPUT KBD;"K";
870   IF Answer$="Y" THEN INPUT "Put paper in the plotter then hit <RETURN>",Whi
ch$
871   GINIT
872   GRAPHICS ON
873   IF Answer$="Y" THEN
874     PLOTTER IS 705,"HPGL"
875     VIEWPORT 0,125,0,100
876     Which_pltr$="Plotter"
877     Penn$="Axes"
878     GOSUB Pen_select
879   ELSE
880     PLOTTER IS CRT,"INTERNAL"
881     Which_pltr$="CRT"
882     VIEWPORT 0,120,26,100
883   END IF
884   Load_ran=Load_max-Load_min
885   T_ran=T_end-T_start
886   WINDOW T_start-.1*(T_ran),T_end,Load_min-.1*Load_ran,Load_max+.13*Load_ran
887   CLIP T_start,T_end,Load_min,Load_max
888   GRID T_ran/10,Load_ran/10,T_start,Load_min,1,1
889   CLIP OFF
890   CSIZE 3
891   LORG 4
892   MOVE (T_start+T_end)/2,Load_max+.08*Load_ran
893   LABEL USING "K";Sample_nr$&"  "&VAL$(Test_temp)&" C"
894   LORG 6
895   FOR I=T_start TO T_end STEP (T_start-T_end)/(-5)
```

```
896     MOVE I,Load_min-.025*Load_ran
897     LABEL USING "K";I
898   NEXT I
899   MOVE .5*(T_start+T_end),Load_min-.07*Load_ran
900   LABEL USING "K";X_axis$
901   LORG 8
902   FOR I=Load_min TO Load_max STEP Load_ran/10
903     MOVE T_start-(.01*(T_end-T_start)),I
904     LABEL USING "K";I
905   NEXT I
906   LORG 4
907   MOVE T_start-(.07*(T_end-T_start)),Load_ran/2+Load_min
908   DEG
909   LDIR 90
910   LABEL USING "K";Y_axis$
911   LDIR 0
912   LORG 4
913   IF Extensometer$="On" THEN
914     Exp_ran=Explotmax-Explot0
915     CLIP T_start+.1*T_ran,T_end,Load_max,Load_max+.1*Load_ran
916     AXES T_ran/10,Load_ran/20,T_start,Load_max
917     CLIP OFF
918     FOR I=T_start TO T_end STEP T_ran/10
919       MOVE I,Load_max+Load_ran*.03
920       LABEL USING "K";(I-Exp_int)/Exp_con
921     NEXT I
922   END IF
923   RETURN
924 Which_msu:  !
925   MASS STORAGE IS ":CS80,700,1"
926   PRINT "Do you want to store/recall data to/from the 3-1/2 floppy?"
927   GOSUB Yes_no
928   IF Answer$="Y" THEN MASS STORAGE IS ":CS80,700"
929   KEY LABELS OFF
930   RETURN
931 Yes_no:  !
932   OFF KEY
933   KEY LABELS OFF
934   FOR Q=1 TO 4
935     ON KEY Q LABEL "YES" GOTO Yess
936     ON KEY Q+4 LABEL "NO" GOTO Noo
937   NEXT Q
938   KEY LABELS ON
939 Yes_no_idle:GOTO Yes_no_idle
940 Yess:Answer$="Y"
941   RETURN
942 Noo:Answer$="N"
943   RETURN
944 Analyze_data:  !
945   PRINT IS 1
946   PRINT "Data analysis section not written yet"
```

```
947   BEEP
948   GOTO Main_menu
949   END
950   SUB Changer(Ara(*),F)
951     FOR I=1 TO 5000
952       Ara(I)=Ara(I)*F
953     NEXT I
954   SUBEND
```

B. DATA REDUCTION PROGRAM

REDUCE is similar in structure to ACQR. The load/time data stored by ACQR is accessed and converted to stress/strain data.

1. Users Guide

The program is used similarly to ACQR. The user recalls the data of interest and plots it on the video screen and then selects 'REDUCE DATA' from the menu. The elastic range of the plot needs to be linearized. This is done through 'INPUT TYPE' by 1) a numerical X-Y input via the keyboard, 2) using the cursor arrows, or 3) by using the mouse. The end points of the line is selected and the last good data point is chosen. The line is then drawn over the plot. If the slope of the plastic zone is not correct, it can be done over or accepted using 'SLOPE OKAY'. The program will remove the grip slippage and re-zero the plot and display the true stress vs. true strain plot that has been "reduced" from the rough load vs. time plot by using 'PLOT TRUE'. Do not select the plotter until you have changed the axes to the appropriate units. The program prints the maximum true stress and trues strain of the data at the top of the graph. Round up to convenient, easily divisible numbers for the axes. Also choose 'TRUE STRESS' and 'TRUE STRAIN' for the axes labels. You may then make a hard copy plot.

2. Source Listing

```
10     ! Program to convert load/time to stress/strain from the Instron 6027
21     ! Revised 07DEC90 Paul Macri
25     ! REDUCE (Stored as S24JUL)
30     DIM Strain(5000),Stress(5000),Sample_nr$[50],Area_i(5000),Extens(5000
35     ! note: Extens is used for inputting strain gage data
37     DIM Stress_engr(5000),Strain_engr(5000),Stress_true(5000)
38     DIM Strain_true(5000)
40     DIM X_axis$[25]
41     CLEAR SCREEN
45 Init_sec:   !
50     Str_rate=1.07 !mm/min
55     Gauge=12.7  !gauge length in mm
60     T_start=0
65     T_end=1000
70     T_total=1000
75     Load_min=0
80     Load_max=2
85     Fs_load_cell=20
90     Test_temp=300
95     X_axis$="Time, minutes"
100    Y_axis$="Load, kN"
```

```
105   Te_co=1 !TENSION ONLY TEST
110   Extensometer$="Off"
115   Ex_convert=1
120   Ex_inter=0
125   Exp_con=1
130   Exp_int=0
135   Explot0=0
140   Explotmax=20
145   Wide=0
150   Thick=0
151   Zzz=0!                  TELLS WHAT THE MAX STRESS/STRAIN IS FOR AXES
153   Xx=0!                   THIS IS FOR THE X,Y AXIS LABELS FOR TRUE/ENGR
154   Old_axes=2!              2 MEANS CREATE AXES FOR A NEW PLOT
155   !                        3 MEANS YOU WANT TO SUPERIMPOSE SEVERAL PLOTS
156   GOSUB Show_set_up
157   !*********************** MAIN MENU  ***************
160 Main_menu:  !
165   BEEP 2000,.1
170   OFF KEY
175   ON KEY 1 LABEL "Change  Set-up" GOTO Set_up_menu!        LINE 3050
180   ON KEY 2 LABEL "Show    Set-up" GOTO Show_set_up_q!      LINE ?
185   ON KEY 3 LABEL "Change  Data" GOTO Change_data!          LINE 315
190   ON KEY 4 LABEL "QUIT" GOTO Stopper!                      LINE 2595
195   ON KEY 5 LABEL "Store   Data" GOTO Store_data!           LINE 1870
200   ON KEY 6 LABEL "Plot    Data" GOTO Plot_data!            LINE 2380
205   ON KEY 7 LABEL "Recall  Old Data" GOTO Recall_data!      LINE 1620
210   ON KEY 8 LABEL "RUN/     REDUCE" GOTO Set_up_ok!
218   IF (Y_axis$="Load, kN" OR Y_axis$="Stress, MPa") AND Fs_load_cell=0 THEN
220     ON KEY 7 LABEL "NEED    LOADCELL" GOTO Load_cell
225     ON KEY 8 LABEL "DATA    NEEDED" GOTO Main_menu
230     BEEP 2000,.1
235     BEEP 2500,.1
240   END IF
245   IF (Sample_area=0 OR Gauge=0) THEN
250     ON KEY 3 LABEL "NEED SA.DIMEN." GOTO S_area_1
255     ON KEY 8 LABEL "DATA    NEEDED" GOTO Main_menu
260     BEEP 2000,.1
265     BEEP 2500,.1
270   END IF
275   IF Sample_nr$="" THEN
280     ON KEY 4 LABEL "IDENTIFYSAMPLE" GOTO Sample_id_m
285     ON KEY 8 LABEL "DATA    NEEDED" GOTO Main_menu
290     BEEP 2000,.1
295     BEEP 2500,.1
300   END IF
301   KEY LABELS ON
310 Main_menu_idle:GOTO Main_menu_idle
312 Change_data:    !*********************** CHANGE DATA   *********
320   OFF KEY
325   ON KEY 1 LABEL "ADD 10%" GOTO C_d_add10!      $$$$$$$ CHANGE LATER
330   ON KEY 2 LABEL "ADD 50%" GOTO C_d_add50
```

```
335   ON KEY 3 LABEL "SUB. 10%" GOTO C_d_sub10
340   ON KEY 4 LABEL "SUB. 50%" GOTO C_d_sub50
345   ON KEY 5 LABEL "MULTIPLYBY 0.1 " GOTO C_d_mulp1
350   ON KEY 6 LABEL "MULTIPLYBY 2 " GOTO C_d_mul2
355   ON KEY 7 LABEL "MULTIPLYBY 10" GOTO C_d_mul10
360   ON KEY 8 LABEL "Convert Units" GOTO Conv_units
365   KEY LABELS ON
370 C_d_spin:GOTO C_d_spin
375 C_d_add10:C_d_mult=1.1
380   GOTO C_d
385 C_d_add50:C_d_mult=1.5
390   GOTO C_d
395 C_d_sub10:C_d_mult=.9
400   GOTO C_d
405 C_d_sub50:C_d_mult=.5
410   GOTO C_d
415 C_d_mulp1:C_d_mult=.1
420   GOTO C_d
425 C_d_mul2:C_d_mult=2
430   GOTO C_d
435 C_d_mul5:C_d_mult=5
440   GOTO C_d
445 C_d_mul10:C_d_mult=10
450 C_d:!*************************** C_D  ***************
455   OFF KEY
460   FOR Q=1 TO 2
465     ON KEY Q LABEL "CHANGE  X-VALUES" GOTO C_d_chg_x!         LINE 495
470     ON KEY Q+2 LABEL "CHANGE  Y-VALUES" GOTO C_d_chg_y!       LINE 505
475     ON KEY Q+4 LABEL "CHANGE  AREAS" GOTO C_d_chg_z!          LINE 515
480   NEXT Q
485   KEY LABELS ON
490 C_d_idle:GOTO C_d_idle
495 C_d_chg_x:CALL Changer(Strain(*),C_d_mult)
500   GOTO Main_menu
505 C_d_chg_y:CALL Changer(Stress(*),C_d_mult)
510   GOTO Main_menu
515 C_d_chg_z:CALL Changer(Area_i(*),C_d_mult)
520   GOTO Main_menu!****************************  CONV_UNI     ******
525 Conv_units:  ! Converts x-axis units from current units to      in, load, etc
530   INPUT "Specify code to use conversion section",Which$
535   IF Which$<>"CODE" AND Which$<>"Code" AND Which$<>"code"      Main_menu
540   ON KEY 1 LABEL "Conv. toLoad-t" GOTO Load_time
545   ON KEY 2 LABEL "Conv. toLoad-ext" GOTO Load_ext
550   ON KEY 3 LABEL "Conv. toLoad-%" GOTO Load_pct
555   ON KEY 4 LABEL "Conv. toLoad-stn" GOTO Load_strain
560   ON KEY 5 LABEL "Conv. toStrs-%" GOTO Stress_pct
565   ON KEY 6 LABEL "Conv. toStrs-ext" GOTO Stress_ext
570   ON KEY 7 LABEL "Conv. toStrs-stn" GOTO Stress_strain
575   ON KEY 8 LABEL "Conv. toTrue S-s" GOTO True_true
580   KEY LABELS ON
585 Conv_units_idle:GOTO Conv_units_idle
```

```
590 Load_time:!
595   GOSUB Conv_time_1
600   GOSUB Conv_load_1
605   GOTO Main_menu
610 Load_ext:  !
615   GOSUB Conv_load_1
620   GOSUB Conv_ext_1
625   GOTO Main_menu
630 Load_pct:!
635   GOSUB Conv_load_1
640   GOSUB Conv_pct_1
645   GOTO Main_menu
650 Load_strain:!
655   GOSUB Conv_load_1
660   GOSUB Conv_strain_1
665   GOTO Main_menu
670 Stress_pct:!
675   GOSUB Conv_stress_1
680   GOSUB Conv_pct_1
685   GOTO Main_menu
690 Stress_ext:!
695   GOSUB Conv_stress_1
700   GOSUB Conv_ext_1
705   GOTO Main_menu
710 Stress_strain:!
715   GOSUB Conv_stress_1
720   GOSUB Conv_strain_1
725   GOTO Main_menu
730 True_true:!
735   PRINT "Not written yet"
740   BEEP 200,.5
745   WAIT !
750   GOTO Main_menu
755 Conv_ext_1:! Converts x-data to extension in mm
760   KEY LABELS OFF
765   IF X_axis$="Elongation, mm" THEN GOTO Conv_ext_2
770   I_conv_x=1
775   IF X_axis$="Time, minutes" THEN
780     X_axis$="Elongation, mm"
785     I_conv_x=Str_rate
790   END IF
795   IF X_axis$="Time, seconds" THEN
800     X_axis$="Elongation, mm"
805     I_conv_x=Str_rate/60
810   END IF
815   IF X_axis$="Elongation, Percent" THEN
820     X_axis$="Elongation, mm"
825     I_conv_x=.01*Gauge
830   END IF
835   IF X_axis$="Strain" THEN
840     X_axis$="Elongation, mm"
```

```
845     I_conv_x=Gauge
850   END IF
855   IF I_conv_x=1 THEN GOSUB Con_err
860   GOSUB Conv_x
865 Conv_ext_2:RETURN
870 Conv_strain_1:! Converts x-data to strain
875   GOSUB Conv_pct_1
880   I_conv_x=.01
885   X_axis$="Strain, mm/mm"
890   GOSUB Conv_x
895   RETURN
900 Conv_pct_1:! Converts x-data to pct strain
905   KEY LABELS OFF
910   IF X_axis$="Elongation, Percent" THEN GOTO Conv_pct_2
915   I_conv_x=1
920   IF X_axis$="Time, minutes" THEN
925     X_axis$="Elongation, Percent"
930     I_conv_x=100*Str_rate/Gauge
935   END IF
940   IF X_axis$="Time, seconds" THEN
945     X_axis$="Elongation, Percent"
950     I_conv_x=100*(Str_rate/60)/Gauge
955   END IF
960   IF X_axis$="Elongation, mm" THEN
965     X_axis$="Elongation, Percent"
970     I_conv_x=100/Gauge
975   END IF
980   IF X_axis$="Strain" THEN
985     X_axis$="Elongation, Percent"
990     I_conv_x=100
995   END IF
1000  IF I_conv_x=1 THEN GOSUB Con_err
1005  GOSUB Conv_x
1010 Conv_pct_2:RETURN
1015 Conv_time_1:! Converts x-data to time in minutes
1020  KEY LABELS OFF
1025  IF X_axis$="Time, minutes" THEN GOTO Conv_time_2
1030  I_conv_x=1
1035  IF X_axis$="Time, seconds" THEN
1040    X_axis$="Time, minutes"
1045    I_conv_x=1/60
1050  END IF
1055  IF X_axis$="Elongation, mm" THEN
1060    X_axis$="Time, minutes"
1065    I_conv_x=1/Str_rate
1070  END IF
1075  IF X_axis$="Elongation, Percent" THEN
1080    X_axis$="Time, minutes"
1085    I_conv_x=(1/Str_rate)*.01*Gauge
1090  END IF
1095  IF X_axis$="Strain" THEN
```

```
1100     X_axis$="Time, minutes"
1105     I_conv_x=(1/Str_rate)*Gauge
1110   END IF
1115   IF I_conv_x=1 THEN GOSUB Con_err
1120   GOSUB Conv_x
1125 Conv_time_2:RETURN
1130 Conv_stress_1:!
1135   GOSUB Conv_load_1
1140   IF Sample_area=0 THEN GOSUB S_area
1145   I_conv_y=1000/Sample_area
1150   Y_axis$="Stress, MPa"
1155   GOSUB Conv_y
1160   RETURN
1165 Conv_load_1:!
1170   IF Y_axis$="Load, kN" THEN Conv_load_2
1175   I_conv_y=1
1180   IF Y_axis$="Volts DC" THEN
1185     Y_axis$="Load, kN"
1190     IF Fs_load_cell=0 THEN INPUT "Full-scale value of load cell?, kN",Fs_loa
d_cell
1195     I_conv_y=Fs_load_cell/10
1200   END IF
1205   IF Y_axis$="Millivolts DC" THEN
1210     Y_axis$="Load, kN"
1215     IF Fs_load_cell=0 THEN INPUT "Full-scale value of load cell?, kN",Fs_loa
d_cell
1220     I_conv_y=Fs_load_cell/10000
1225   END IF
1230   IF Y_axis$="Stress, MPa" THEN
1235     Y_axis$="Load, kN"
1240     IF Sample_area=0 THEN GOSUB S_area
1245     I_conv_y=Sample_area
1250   END IF
1255   IF I_conv_y=1 THEN GOSUB Con_err
1260   GOSUB Conv_y
1265 Conv_load_2:RETURN
1270 Conv_x:!
1275   FOR I=0 TO 5000
1280     Strain(I)=Strain(I)*I_conv_x
1285   NEXT I
1290   RETURN
1295 Conv_y: !
1300   FOR I=0 TO 5000
1305     Stress(I)=Stress(I)*I_conv_y
1310   NEXT I
1315   RETURN
1320 Con_err:!
1325   BEEP 200,.5
1330   PRINTER IS 1
1335   PRINT "*****CAUTION*****No conversion"
1340   WAIT 3
```

```
1345  RETURN
1350 Load_time_2: !
1355  IF Y_axis$="Load, kN" THEN Load_time_3
1360  I_conv_y=1
1365  IF Y_axis$="Volts DC" THEN
1370    Y_axis$="Load, kN"
1375    IF Fs_load_cell=0 THEN INPUT "Full-scale value of load cell?, kN",Fs_loa
d_cell
1380    I_conv_y=Fs_load_cell/10
1385  END IF
1390  IF Y_axis$="Millivolts DC" THEN
1395    Y_axis$="Load, kN"
1400    IF Fs_load_cell=0 THEN INPUT "Full-scale value of load cell?, kN",Fs_loa
d_cell
1405    I_conv_y=Fs_load_cell/10000
1410  END IF
1415  IF Y_axis$="Stress, MPa" THEN
1420    Y_axis$="Load, kN"
1425    IF Sample_area=0 THEN GOSUB S_area
1430    I_conv_y=Sample_area
1435  END IF
1440  IF I_conv_y=1 THEN GOSUB Con_err
1445  GOSUB Conv_y
1450 Load_time_3:RETURN
1455 Sample_id_s: !****************************  SAMPLE_ID_S *************
1460  ON KEY 1 LABEL "IdentifySample" GOTO Sample_id_s_2
1465  ON KEY 2 LABEL "IdentifySample" GOTO Sample_id_s_2
1470  ON KEY 3 LABEL "Change  Temp" GOTO Chg_test_temp
1475  ON KEY 4 LABEL "Change  Temp" GOTO Chg_test_temp
1480  FOR Q=5 TO 8
1485    ON KEY Q LABEL "Change  Dimen's" GOTO S_area_2
1490  NEXT Q
1495 Sample_id_spin:GOTO Sample_id_spin
1500 Chg_test_temp:!
1505  Var=Test_temp
1510  GOSUB Var_change
1515  Test_temp=Var
1520  GOTO Set_up_menu
1525 Sample_id_s_2: !
1530  GOSUB Sample_id
1535  GOTO Set_up_menu
1540 Sample_id_m: !
1545  GOSUB Sample_id
1550  GOTO Main_menu
1555 Sample_id: !
1560  KEY LABELS OFF
1565  INPUT "Identify sample 50 characters max",Sample_nr$
1570  RETURN
1575 S_area_1: !
1580  GOSUB S_area
1585  GOTO Main_menu
```

```
1590 S_area_2: !
1595  GOSUB S_area
1600  GOTO Set_up_menu
1605 Show_set_up_q: !
1610  GOSUB Show_set_up
1615  GOTO Main_menu
1620 Recall_data:!**************** RECALL_DATA ****************
1625  GOSUB Re_data
1626  GOSUB Show_set_up_q
1630  GOTO Plot_data
1635 Re_data:!******************** RE_DATA  **********************
1640  GOSUB Which_msu
1641  ON ERROR GOTO Input_err
1642  INPUT "File to be used? Don't type suffix X,Y,orZ.",File_name$
1643  Xfile$=File_name$&"B"
1644  Yfile$=File_name$&"C"
1645  Zfile$=File_name$&"Z"
1646  Qfile$=File_name$&"Q"
1647  ASSIGN @Path1 TO Xfile$
1648  ASSIGN @Path2 TO Yfile$
1649  ASSIGN @Path3 TO Zfile$
1650  ASSIGN @Path4 TO Qfile$
1651! ON END @Path3 GOTO Plot_data
1652  OFF ERROR
1653  ON ERROR GOTO 1655
1654  ENTER @Path1;Strain(*)
1655  OFF ERROR
1656  ON ERROR GOTO 1658
1657  ENTER @Path2;Stress(*)
1658  OFF ERROR
1659  ON ERROR GOTO 1663
1660  E_c=Ex_convert
1661  E_i=Ex_inter
1662  ENTER @Path3;Sample_nr$,X_axis$,Y_axis$,Dia,Wide,Thick,Gauge,T_start,T_end
,Load_min,Load_max,Fs_load_cell,Te_co,Str_rate,Extensometer$,E_c,E_i,Test_temp
1663  OFF ERROR
1664  ON ERROR GOTO 1667
1665  ENTER @Path4;Extens(*)
1666  OFF ERROR
1667  ASSIGN @Path4 TO *
1668  ASSIGN @Path1 TO *
1669  ASSIGN @Path2 TO *
1670  ASSIGN @Path3 TO *
1795  RETURN
1800 Input_err: !*********************INPUT_ERR ********************
1805  PRINTER IS 1
1810  IF ERRN=56 THEN
1815    PRINTER IS 701
1820    CAT
1825    FOR Q=1 TO 5
1830      PRINT
```

```
1835     NEXT Q
1840     PRINTER IS 1
1845   END IF
1850   PRINT USING "@,#"
1855   BEEP
1860   PRINT ERRM$
1865   GOTO Recall_data
1870 Store_data:!**************** STORE_DATA *******************
1875   GOSUB Which_mau
1880   ON ERROR GOTO Store_err
1885   INPUT "File to be used? Don't type suffix B,C,or Z.",File_name$
1890   Xfile$=File_name$&"B"
1891   Yfile$=File_name$&"C"
1892   Zfile$=File_name$&"Z"
1893   Qfile$=File_name$&"Q"
1894   ASSIGN @Path1 TO Xfile$
1895   ASSIGN @Path2 TO Yfile$
1896   ASSIGN @Path3 TO Zfile$
1897   ASSIGN @Path4 TO Qfile$
1898   ON END @Path4 GOTO Main_menu
1899   OFF ERROR
1900   ON ERROR GOTO 1902
1901   OUTPUT @Path1;Strain(*)
1902   OFF ERROR
1903   ON ERROR GOTO 1905
1904   OUTPUT @Path2;Stress(*)
1905   OFF ERROR
1906   ON ERROR GOTO 1910
1907   E_c=Ex_convert
1908   E_i=Ex_inter
1909   OUTPUT @Path3;Sample_nr$,X_axis$,Y_axis$,Dia,Wide,Thick,Gauge,T_start,T_en
d,Load_min,Load_max,Fs_load_cell,Te_co,Str_rate,Extensometer$,E_c,E_i,Test_temp
1910   OFF ERROR
1911   ON ERROR GOTO 1914
1912   OUTPUT @Path4;Extens(*)
1913   OFF ERROR
1914   ASSIGN @Path4 TO *
1915   ASSIGN @Path1 TO *
1916   ASSIGN @Path2 TO *
1917   ASSIGN @Path3 TO *
2030   MASS STORAGE IS ":CS80,700,1"
2035   GOTO Main_menu
2040 Store_err: !***************************  STORE_ERR ****************
2045   PRINTER IS 1
2050   IF ERRN=56 THEN
2055     OFF ERROR
2060     PRINT "File not found. Below is a list of current files."
2065     CAT
2070     FOR Q=1 TO 5
2075       PRINT
2080     NEXT Q
```

```
2085    PRINT "Would you like to create a new file?"
2090    GOSUB Yes_no
2095    IF Answer$="Y" THEN
2100      PRINT "Insert data disk"
2105      BEEP
2110      INPUT "File name?",File_name$
2115 New_file:     !
2120      ON ERROR GOTO Disk_full
2125      PRINT "Creating new files......................"
2130      CREATE BDAT File_name$&"D",8,5000
2135      CREATE BDAT File_name$&"C",8,5000
2140      CREATE BDAT File_name$&"Z",1,5000
2145      CREATE BDAT File_name$&"Q",1,5000
2150      OFF ERROR
2155    ELSE
2160      GOTO Store_data
2165    END IF
2170  ELSE
2175    PRINT ERRM$
2180    OFF ERROR
2185    PRINT "Do you want to try again?"
2190    GOSUB Yes_no
2195    IF Answer$="Y" THEN Store_data
2200    GOTO Main_menu
2205  END IF
2210  PRINT USING "@,#"
2215  BEEP
2220  GOTO Store_data
2225 Disk_full: !***************************  DISK_FULL ************
2230  OFF ERROR
2235  PRINT "This disk is full. Do you want to replace it with a new disk?"
2240  GOSUB Yes_no
2245  IF Answer$="N" THEN Store_data
2250  GOTO New_file
2255 Print_data: !************************ PRINT_DATA *****************
2260  PRINTER IS 701
2265  GOSUB Show_set_up_2
2270  PRINTER IS 1
2275  GOTO Main_menu
2280 Plot_data: !*********************** PLOT_DATA *********************
2281  IF Old_axes=3 THEN GOSUB Plot_data_21       TO MAKE A SUPERIMPOSED PLOT
2282  IF Xx=2 THEN
2283    X_axis$="Engineering Strain"
2284    Y_axis$="Engineering Stress, MPa"
2285  END IF
2286  IF Xx=3 THEN
2287    X_axis$="True Strain"
2288    Y_axis$="True Stress, MPa"
2289  END IF
2290  GOSUB Plot_set_up
2291  L_type=0
```

```
2292 Next_curve: !
2293  L_type=L_type+1
2294  LINE TYPE L_type
2295  OFF KEY
2296  ON KEY 1 LABEL "ContinuePlot" GOTO Plot_data_2
2297  ON KEY 2 LABEL "CHANGE  MAINAXES" GOTO Plot_axes
2298  !ON KEY 3 LABEL "CHANGE  SUB-AXES" GOTO Sub_axes
2299  ON KEY 3 LABEL "                    " GOTO Sub_axes
2300  ON KEY 4 LABEL "NEW      PLOT" GOTO Main_menu
2301  ON KEY 5 LABEL "Main     Menu" GOTO Main_menu
2302  ON KEY 6 LABEL "Print    Data" GOTO Print_data
2303  IF Extensometer$="ON" THEN
2304    ON KEY 7 LABEL "LOAD-    TIME" GOTO Plot_data_2
2305  ELSE
2306    ON KEY 7 LABEL "Stress- Strain" GOTO Stress_strain
2307  END IF
2308  ON KEY 8 LABEL "REDUCE  DATA" GOTO Data_red_menu
2309  KEY LABELS ON
2310    IF Xx=3 THEN PRINT "TRUE STRESS (MAX)=";Stress_max;" TRUE STRAIN (MAX)="
;Strain_max
2311    IF Xx=2 THEN PRINT "ENGR STRESS (MAX)=";Stress_max;" ENGR STRAIN (MAX)="
;Strain_max
2313 Plot_data_idle:GOTO Plot_data_idle
2314 Plot_axes: !**************************  PLOT_AXES **********
2315  GOSUB Axes_u
2316  GOSUB Start_t
2317  GOSUB Plot_set_up
2318  GOTO Plot_data_2
2319 Sub_axes: !***************************  SUB_AXES *************
2320  GOSUB Ex_plt_cnv
2321  GOSUB Plot_set_up
2322  GOTO Plot_data_2
2323 Plot_data_3: !*********************** PLOT_DATA_3 *********
2324  KEY LABELS OFF
2325  IF Answer$="Y" THEN GOSUB Pen_select
2326  FOR I=1 TO 5000
2327    Explot=Extens(I)*Exp_con+Exp_int
2328    IF I=1 OR Explot=T_start THEN MOVE Explot,Stress(I)
2329    IF Explot<T_start OR Explot>T_end THEN End_plot_3
2330    PLOT Explot,Stress(I)
2331 End_plot_3: !
2332  NEXT I
2333  IF Answer$="Y" THEN PEN 0
2334  GOTO Next_curve
2335 Re_data_1: !*************************** RE_DATA_1 ***********
2336  GOSUB Re_data
2337 Plot_data_2: !*********************** PLOT_DATA_2 ***********
2338  IF Which_pltr$="Plotter" THEN GOSUB Pen_select
2340  KEY LABELS OFF
2342  FOR I=1 TO 5000
2343  IF I=N_points THEN GOTO Next_curve
```

```
2345    IF I=1 OR Strain(I)=T_start THEN MOVE Strain(I),Stress(I)
2347    IF Strain(I)<T_start THEN End_curve
2348    IF Strain_engr(I)<T_start THEN End_curve
2349    IF Te_co=1 AND (Stress(I)>Load_max OR Stress(I)<Load_min) THEN GOTO End_
curve
2350    IF Te_co=3 AND (Stress(I)<Load_max OR Stress(I)>Load_min) THEN GOTO End_
curve
2351    IF Strain(I)>T_end OR Strain_engr(I)>T_end THEN
2352      I=5000
2353      GOTO End_curve
2354    END IF
2355    IF I>N_points AND Strain(I)=0 THEN
2356    GOTO Next_curve
2357    END IF
2359    IF Xx=0 OR Xx=3 THEN PLOT Strain(I),Stress(I)
2360    IF Xx=2 THEN PLOT Strain_engr(I),Stress_engr(I)
2361 End_curve:   !
2362  NEXT I
2363  IF Answer$="Y" THEN PEN 0
2364  GOTO Next_curve
2365 Show_set_up_1: !********************** SHOW_SET_UP_1 *****************
2366  GOSUB Show_set_up
2367  GOTO Main_menu_idle
2368 Stopper:!****************************** STOPPER************************
2369  PRINTER IS 1
2370  KEY LABELS OFF
2371  PRINT "Do you want use this program again?"
2372  GOSUB Yes_no
2373  IF Answer$="N" THEN LOAD "MSLABS"
2374  IF Answer$="Y" THEN GOTO Starter
2376  STOP
2377 Load_cell: !************************* LOAD_CELL ******************
2378  KEY LABELS OFF
2379  INPUT "What is the full-scale load value in kN?",Fs_load_cell
2380  GOTO Main_menu
2381 S_area: !
2382  OFF KEY
2383  FOR Q=1 TO 4
2384    ON KEY Q LABEL "round   sample" GOTO Round
2385    ON KEY Q+4 LABEL "rect.   sample" GOTO Rect
2386  NEXT Q
2387  KEY LABELS ON
2388 S_area_idle:GOTO S_area_idle
2389 Round:!
2390  KEY LABELS OFF
2391  INPUT "Sample diameter, mm?",Dia
2392  Sample_area=(PI/4)*(Dia^2)
2393  GOTO G_length
2394 Rect: !
2395  KEY LABELS OFF
2396  INPUT "Sample width, mm?",Wide
```

```
2397  INPUT "Sample thickness, mm?",Thick
2398  Sample_area=Wide*Thick
2399 G_length:!
2400  PRINT "Default gauge length is ",Gauge;" mm. Hit <RETURN> to accept"
2401  INPUT "Gauge length, mm?",Gauge
2402  RETURN
2403 Show_set_up:!**************** SHOW_SET_UP ************************
2404  PRINTER IS 1
2405 Show_set_up_2: !************* SHOW_SET_UP_2 ****************
2406  PRINT USING "@,#"
2407  PRINT "Current set up is as follows:"
2408  PRINT "   Sample Parameters:"
2409  IF Sample_nr$="" THEN
2410    PRINT "      Sample unnamed"
2411  ELSE
2412    PRINT "      Sample: ";Sample_nr$
2413  END IF
2414  IF Gauge<>0 THEN
2415    PRINT "      Gauge length is ";Gauge;" mm"
2416  ELSE
2417    PRINT "      No gauge length specified"
2418  END IF
2419  IF Dia<>0 THEN Sample_area=(PI/4)*(Dia^2)
2420  IF Thick<>0 AND Wide<>0 THEN Sample_area=Wide*Thick
2421  IF Samole_area<>0 THEN
2422    IF Dia<>0 THEN
2423      PRINT "      Using round sample with a diameter of ";Dia;" mm"
2424    ELSE
2425      PRINT "      Using flat sample ";Wide;" mm wide X ";Thick;"mm thick"
2426    END IF
2427    PRINT "      Sample area is ";Sample_area;" mm^2"
2428  ELSE
2429    PRINT "      Sample dimensions are incomplete"
2430  END IF
2431  PRINT
2432  PRINT "   Testing Parameters:"
2433  PRINT "      Crosshead speed";Str_rate;" mm/min"
2434  PRINT "      Full-scale range of load cell is set for ";Fs_load_cell;"kN"
2435  PRINT "      Hold time at finish ";Hold_time;" min"
2436  IF Te_co=1 THEN PRINT "      Tension only test"
2437  IF Te_co=2 THEN PRINT "      Tension/compression test"
2438  IF Te_co=3 THEN PRINT "      Compression only test"
2439  PRINT "       Extensometer/Strain Gage is ";Extensometer$
2440  IF Extensometer$="On" THEN
2441    PRINT "      Extensometer/Strain gage conversion factor is ";Ex_convert
2442    PRINT "      Extensometer/Strain gage intercept is ";Ex_inter
2443    PRINT "      Strain shown will be from ";Explot0;" to ";Explotmax
2444  END IF
2445  PRINT "      Test temperature is ";Test_temp;" deg C or ";Test_temp+273.16;
" K"
2446  PRINT
```

```
2447  PRINT "   Plotting Parameters:"
2448  IF X_axis$="Time, minutes" THEN PRINT "     Start time ";T_start;" min   F
inish time ";T_end;" min"
2449  IF X_axis$="Time, seconds" THEN PRINT "     Start time ";T_start;" sec   F
inish time ";T_end;" sec"
2450  IF X_axis$="Elongation, mm" THEN PRINT "     Starting Elongation ",T_start
;" mm    Finish Elongation ";T_end;" mm"
2451  IF X_axis$="Elongation, Percent" THEN PRINT "     Starting Elongation ",T
start;" %    Finish Elongation ";T_end;" %"
2452  IF X_axis$="Strain" OR Xx=2 OR Xx=3 THEN PRINT "     Starting strain ",T_s
tart;" Finish strain ";T_end
2453  IF Y_axis$="Volts DC" THEN PRINT "     Y-axis minimum is ";Load_min;" volt
s  and Y-axis maximum is ";Load_max;" volts"
2454  IF Y_axis$="Millivolts DC" THEN PRINT "     Y-axis minimum is ";Load_min;"
 millivolts  and Y-axis maximum is ";Load_max;" millivolts"
2455  IF Y_axis$="Load, kN" THEN PRINT "     Load ranges from ",Load_min;" kN to
 ";Load_max;" kN  (neg means compression)"
2456  IF Y_axis$="Stress, MPa" OR Xx=2 OR Xx=3 THEN
2457    PRINT "     Stress ranges from ",Load_min;" MPa to ";Load_max;" MPa"
2458    PRINT "     (neg means compression)"
2459  END IF
2460  RETURN
2461 Set_up_menu: !
2462  BEEP 2000,.2
2463  BEEP 2100,.2
2464  OFF KEY
2465  GOSUB Show_set_up
2466  ON KEY 1 LABEL "Sample  Params" GOTO Sample_id_s
2467  ON KEY 2 LABEL "Sample  Params" GOTO Sample_id_s
2468  ON KEY 3 LABEL "Test    Params" GOTO Test_params
2469  ON KEY 4 LABEL "Test    Params" GOTO Test_params
2470  ON KEY 5 LABEL "PlottingParams" GOTO Axes_units
2471  ON KEY 6 LABEL "PlottingParams" GOTO Axes_units
2472  ON KEY 7 LABEL "" GOTO Set_up_idle
2473  ON KEY 8 LABEL "SETUP   OK" GOTO Main_menu
2474  IF Sample_nr$="" THEN ON KEY 8 LABEL "IDENTIFYSAMPLE" GOTO Sample_id_s
2475  !SEE LINE 2455 ************************************************
2476  IF (Y_axis$="Load, kN" OR Y_axis$="Stress, MPa" OR Xx=2 OR Xx=3) AND Fs_lo
ad_cell=0 THEN
2477    ON KEY 8 LABEL "NEED    LOADCELL" GOTO Load_cell
2478    BEEP 2000,.1
2479  END IF
2480  IF ((Y_axis$="Stress, MPa" OR Xx=2 OR Xx=3) AND Sample_area=0) OR (X_axis$
="Elongation, %" OR X_axis$="Strain" OR Xx=2 OR Xx=3 AND Gauge=0) THEN
2481    ON KEY 8 LABEL "SAMPLE  DIMEN." GOTO S_area_2
2482  END IF
2483  IF (X_axis$="Elongation, mm" OR X_axis$="Elongation, %" OR X_axis$="Strain
" OR Xx=2 OR Xx=3) AND Str_rate=0 THEN
2484    ON KEY 7 LABEL "X-head  Speed" GOTO Rates
2485    ON KEY 8 LABEL "" GOTO Rates
2486  END IF
```

```
2487  KEY LABELS ON
2488 Set_up_idle:GOTO Set_up_idle
2489 Test_params: !****************************** TEST_PARAMS ****************
2490  ON KEY 1 LABEL "Change  X-head V" GOTO Rates
2491  ON KEY 2 LABEL "Change  Load Cell" GOTO Load_cell
2492  ON KEY 3 LABEL "Tension/Compression" GOTO Ten_com
2493  ON KEY 4 LABEL "Hold    Time" GOTO Holds
2494  ON KEY 5 LABEL "Extens. Toggle" GOTO Extoggle_1
2495  FOR Q=6 TO 8
2496    ON KEY Q LABEL "" GOTO Test_par_spin
2497  NEXT Q
2498 Test_par_spin:GOTO Test_par_spin
2499 Extoggle_1: !
2500  GOSUB Ex_toggle
2501  GOSUB Ex_cnv
2502  GOSUB Ex_plt_cnv
2503  GOTO Set_up_menu
2504 G_l_set_up: !
2505  Var=Gauge
2506  PRINT "Changing gauge length"
2507  GOSUB Var_change
2508  Gauge=Var
2509  GOTO Set_up_menu
2510 Start_t: !
2511  Var=T_start
2512  PRINT "Changing minimum x-axis value:"
2513  GOSUB Var_change
2514  T_start=Var
2515  Var=T_end
2516  PRINT "Changing maximum x-axis value:"
2517  GOSUB Var_change
2518  T_end=Var
2519  T_ran=T_end-T_start
2520 Load_vals: !
2521  Var=Load_min
2522  PRINT "Changing minimum y-axis value:"
2523  GOSUB Var_change
2524  Load_min=Var
2525  Var=Load_max
2526  PRINT "Changing maximum y-axis value:"
2527  GOSUB Var_change
2528  Load_max=Var
2529  Load_ran=Load_max-Load_min
2530  RETURN
2531 Axes_units: !********************** AXES_UNITS ****************
2532  GOSUB Axes_u
2533  GOSUB Start_t
2534  GOTO Set_up_menu
2535 Axes_u: !********************** AXES_U **********************
2536  KEY LABELS OFF
2537  OFF KEY
```

```
2538  PRINT "Select label for X-axis. Default is time in minutes"
2539  ON KEY 1 LABEL "Time    Minutes" GOTO Time_min
2540  ON KEY 2 LABEL "Time    Seconds" GOTO Time_sec
2541  ON KEY 3 LABEL "Elong.  mm" GOTO Elong_mm
2542  ON KEY 4 LABEL "Elong.  %" GOTO Elong_pct
2543  ON KEY 5 LABEL " True    Strain" GOTO Strain_axis
2544  ON KEY 6 LABEL " Engr    Strain" GOTO Strain_axis
2545  FOR Q=7 TO 8
2546    ON KEY Q LABEL "" GOTO Axes_idle
2547  NEXT Q
2548  KEY LABELS ON
2549 Axes_idle:GOTO Axes_idle
2550 Time_min:!
2551  X_axis$="Time, minutes"
2552  GOTO Set_up_y_axis
2553 Time_sec:!
2554  X_axis$="Time, seconds"
2555  GOTO Set_up_y_axis
2556 Elong_mm:!
2557  X_axis$="Elongation, mm"
2558  GOTO Set_up_y_axis
2559 Elong_pct:!
2560  X_axis$="Elongation, Percent"
2561  GOTO Set_up_y_axis
2562 Strain_axis:!
2563  X_axis$="Strain"
2564  IF Xx=2 THEN X_axis$="Engineering Strain"
2565  IF Xx=3 THEN X_axis$="True Strain"
2566 Set_up_y_axis:!
2567  OFF KEY
2568  PRINT "Select label for Y-axis. Default is load"
2569  ON KEY 3 LABEL "Volts   DC" GOTO Volts_y
2570  ON KEY 5 LABEL "mV      DC" GOTO Mv_y
2571  ON KEY 1 LABEL "Load, N" GOTO Load_y
2572  ON KEY 2 LABEL "T Stress   MPa  " GOTO Stress_y
2573  ON KEY 3 LABEL "E Stress   MPa  " GOTO Stress_y
2574  FOR Q=5 TO 8
2575    ON KEY Q LABEL "" GOTO Y_ax_idle
2576  NEXT Q
2577  KEY LABELS ON
2578 Y_ax_idle:GOTO Y_ax_idle
2579 Volts_y:!
2580  Y_axis$="Volts DC"
2581  RETURN
2582 Mv_y:!
2583  Y_axis$="Millivolts DC"
2584  RETURN
2585 Load_y:!
2586  Y_axis$="Load, kN"
2587  RETURN
2588 Stress_y:!
```

```
2589  IF Xx=2 THEN Y_axis$="Engr Stress  MPa    "
2590  IF Xx=3 THEN Y_axis$="True Stress  MPa    "
2591  RETURN
2592 Rates: !
2593  Var=Str_rate
2594  PRINT "Editing crosshead speed: give value in mm/min"
2595  GOSUB Var_change
2596  Str_rate=Var
2597  GOTO Set_up_menu
2598 Holds: !
2599  GOSUB Holds1
2600  GOTO Set_up_menu
2601 Holds1: !
2602  PRINT "Change hold time?"
2603  GOSUB Yes_no
2604  IF Answer$="Y" THEN
2605    Var=Hold_time
2606    GOSUB Var_change
2607    Hold_time=Var
2608  END IF
2609  RETURN
2610 Ex_toggle: !
2611  PRINT "Toggle extensometer?"
2612  GOSUB Yes_no
2613  IF Answer$="N" THEN GOTO Ex_cnv
2614  IF Extensometer$="Off" THEN
2615    Extensometer$="On"
2616  ELSE
2617    Extensometer$="Off"
2618  END IF
2619  RETURN
2620 Ex_cnv: !
2621  IF Extensometer$="On" THEN
2622    PRINT "Change conversion factor?"
2623    GOSUB Yes_no
2624    IF Answer$="Y" THEN
2625      Var=Ex_convert
2626      GOSUB Var_change
2627      Ex_convert=Var
2628    END IF
2629    PRINT "Change intercept?"
2630    GOSUB Yes_no
2631    IF Answer$="Y" THEN
2632      Var=Ex_inter
2633      GOSUB Var_change
2634      Ex_inter=Var
2635    END IF
2636  END IF
2637  RETURN
2638 Ex_plt_cnv: !
2639  IF Extensometer$="On" THEN
```

```
2640    PRINT "Change minimum strain plotted?"
2641    GOSUB Yes_no
2642    IF Answer$="Y" THEN
2643      Var=Explot0
2644      GOSUB Var_change
2645      Explot0=Var
2646    END IF
2647    PRINT "Change maximum strain plotted?"
2648    GOSUB Yes_no
2649    IF Answer$="Y" THEN
2650      Var=Explotmax
2651      GOSUB Var_change
2652      Explotmax=Var
2653    END IF
2654    Exp_con=(T_start-T_end)/(Explot0-Explotmax)
2655    Exp_int=T_start-Explot0*Exp_con
2656  END IF
2657  RETURN
2658 Ten_com: !
2659  KEY LABELS OFF
2660  PRINT "TENSION, TENSION/COMPRESSION OR COMPRESSION TEST?"
2661  BEEP 2000,.1
2662  OFF KEY
2663  ON KEY 1 LABEL "TENSION" GOTO Ten_only
2664  ON KEY 2 LABEL "TENSION" GOTO Ten_only
2665  ON KEY 3 LABEL "" GOTO Ten_idle
2666  ON KEY 4 LABEL "TENSION/COMPRESS" GOTO Ten_and_com
2667  ON KEY 5 LABEL "TENSION/COMPRESS" GOTO Ten_and_com
2668  ON KEY 6 LABEL "" GOTO Ten_idle
2669  ON KEY 7 LABEL "COMPRESS" GOTO Com_only
2670  ON KEY 8 LABEL "COMPRESS" GOTO Com_only
2671  KEY LABELS ON
2672 Ten_idle:GOTO Ten_idle
2673 Ten_only:Te_co=1
2674  GOTO Set_up_menu
2675 Ten_and_com:Te_co=2
2676  GOTO Set_up_menu
2677 Com_only:Te_co=3
2678  GOTO Set_up_menu
2679 Var_change:!
2680  INPUT "Type in desired value",Var
2681  PRINTER IS 1
2682  PRINT Var;"Is this OK?"
2683  GOSUB Yes_no
2684  IF Answer$="N" THEN Var_change
2685  RETURN
2686  OFF KEY
2687  KEY LABELS ON
2688  ON KEY 1 LABEL "ADD 100" GOTO Hun_more!$$$$$$$$$$$$$$$$$$$ CHANGE LATER
2689  ON KEY 2 LABEL "ADD 10" GOTO Ten_more
2690  ON KEY 3 LABEL "ADD 1" GOTO One_more
```

```
2691  ON KEY 4 LABEL "OK" GOTO Var_return
2692  ON KEY 5 LABEL "SUBTRACT 1" GOTO One_less
2693  ON KEY 6 LABEL "MULTIPLYBY .1" GOTO Mult_pt_1
2694  ON KEY 7 LABEL "MULTIPLYBY 10" GOTO Mult_10
2695  ON KEY 8 LABEL "SET TO   0" GOTO Var_zero
2696  PRINTER IS 1
2697  PRINT "Current value is ";Var
2698 Var_idle:GOTO Var_idle
2699 Var_return:         !
2700  RETURN
2701 Var_zero:!
2702  Var=0
2703  GOTO Var_change
2704 Hun_more:
2705  Var=Var+100
2706  GOTO Var_change
2707 Ten_more:!
2708  Var=Var+10
2709  GOTO Var_change
2710 One_more:!
2711  Var=Var+1
2712  GOTO Var_change
2713 Mult_pt_1:!
2714  Var=Var*.10
2715  GOTO Var_change
2716 Mult_10:!
2717  Var=Var*10
2718  GOTO Var_change
2719 One_less:!
2720  Var=Var-1
2721  GOTO Var_change
2722  GOTO Set_up_menu
2723 Set_up_ok:!*********************** SET_UP_OK *******************
2724          PRINT " "
2725  PRINT "DO YOU WISH TO:"
2726          PRINT " "
2727  PRINT "               RUN A TEST        OR            REDUCE DATA       ?"
2728  PRINT "                 <YES>                              <NO>"
2729  GOSUB Yes_no
2730  IF Answer$="Y" THEN GOTO Init_daq
2731  IF Answer$="N" THEN GOSUB Plot_data
2740 Init_daq:!
2742  CLEAR SCREEN
2743          PRINT " "
2744  PRINT "WHAT IS TIME FRAME FOR DATA COLLECTION   (DURATION OF EXPERIMENT)?"
2745          PRINT " "
2746  OFF KEY
2747  ON KEY 1 LABEL "   15    MINUTES" GOTO Test_duration
2748  ON KEY 2 LABEL "  HALF     HOUR  " GOTO Test_duration
2749  ON KEY 3 LABEL "  ONE      HOUR  " GOTO Test_duration
2750  ON KEY 4 LABEL "  TWO      HOURS " GOTO Test_duration
```

```
2751  ON KEY 5 LABEL "  FOUR    HOURS " GOTO Test_duration
2752  ON KEY 6 LABEL " EIGHT    HOURS " GOTO Test_duration
2753  ON KEY 7 LABEL "  HALF     DAY  " GOTO Test_duration
2754  ON KEY 8 LABEL "  FULL     DAY  " GOTO Test_duration
2755  KEY LABELS ON
2756 Runn_idle:GOTO Runn_idle
2757 Test_duration: !              FEED THIS LATER TO SET UP NUMBER,
2758  KEY LABELS OFF!              AND FREQUENCY OF DATA POINTS
2760  GOSUB Plot_set_up!            AND FREQUENCY OF DATA COLLECTION
2761  OUTPUT 709;"CLR"
2762  OUTPUT 709;"USE 000"
2763  PRINTER IS 1
2764 Re_test: !
2765 Acq_data:!**************************** ACQ_DATA **************
2766 IF Which_pltr$="CRT" THEN
2767    Penn$="Data"
2768    GOSUB Pen_select
2769  END IF
2770  FOR Q=1 TO 4
2771    ON KEY Q LABEL "TEST    COMPLETE" GOTO Test_done
2772    ON KEY Q+4 LABEL "RE-STARTTEST" GOTO Re_test
2773  NEXT Q
2774  KEY LABELS ON
2775  T_total=T_end-T_start
2776  T_convert=1 !assumes x-axis is in seconds
2777  IF X_axis$="Time, minutes" THEN T_convert=1/60
2778  IF X_axis$="Elongation, mm" THEN T_convert=Str_rate/60
2779  IF X_axis$="Elongation, %" THEN T_convert=(Str_rate/Gauge)*(100/60)
2780  IF X_axis$="Strain" THEN T_convert=(Str_rate/60)/Gauge
2781  IF X_axis$="Engineering Strain" THEN T_convert=(Str_rate/60)/Gauge
2782  IF X_axis$="True Strain" THEN T_convert=(Str_rate/60)/Gauge
2783  L_convert=1 !assumes DCV is output
2784  IF Y_axis$="Millivolts DC" THEN L_convert=1000
2785  IF Y_axis$="Load, kN" THEN L_convert=Fs_load_cell/10
2786  IF Y_axis$="Stress, MPa" THEN L_convert=(Fs_load_cell*100)/Sample_area
2787  IF Y_axis$="Engr Stress  MPa   " THEN L_convert=(Fs_load_cell*100)/Sample_
area
2788  IF Y_axis$="True Stress  MPa   " THEN L_convert=(Fs_load_cell*100)/Sample_
area
2789  KEY LABELS OFF
2790  INPUT "Hit <RETURN> when ready to proceed.",Which$
2791  KEY LABELS ON
2792  T_0=TIMEDATE   !Time is measured in seconds then converted to desired unit
2793  LORG 5
2794  FOR I=0 TO 5000
2795    REPEAT
2796      T_i=(TIMEDATE-T_0)*T_convert
2797    UNTIL T_i>=(T_total/5000)*(I)
2798    Strain(I)=T_i
2799    OUTPUT 709;"CONFMEAS DCV,214"
2800    ENTER 709;Stress(I)
```

```
2801     Stress(I)=Stress(I)*L_convert
2802     PLOT Strain(I),Stress(I)
2803     IF Extensometer$="On" THEN
2804       OUTPUT 709;"CONFMEAS DCV,215"
2805       ENTER 709;Extens(I)
2806       Extens(I)=Extens(I)*Ex_convert+Ex_inter!CONVERTS TO STRAIN VALUES
2807       Explot=Extens(I)*Exp_cont+Exp_int!CONVERTS STRAIN TO PLOTABLE VALUES
2808       MOVE Explot,Stress(I)
2809       LABEL USING "K";"*"
2810     END IF
2811   NEXT I
2812 Test_done: !
2813   N_points=I
2815   OFF KEY
2816   FOR Q=1 TO 4
2817     ON KEY Q LABEL "              " GOTO Dumper
2818     ON KEY Q+4 LABEL "Main    Menu" GOTO Main_menu
2819   NEXT Q
2820 T_d_idle:GOTO T_d_idle
2821 Pen_select: !
2822   ON KEY 1 LABEL "Pen 1" GOTO P1
2823   ON KEY 2 LABEL "Pen 2" GOTO P2
2824   ON KEY 3 LABEL "Pen 3" GOTO P3
2825   ON KEY 4 LABEL "Pen 4" GOTO P4
2826   ON KEY 5 LABEL "Pen 5" GOTO P5
2827   ON KEY 6 LABEL "Pen 6" GOTO P6
2828   ON KEY 7 LABEL "Drawing "&Penn$ GOTO Pen_select_idle
2829   ON KEY 8 LABEL "Drawing "&Penn$ GOTO Pen_select_idle
2830   KEY LABELS ON
2831   BEEP 2000,.1
2832 Pen_select_idle:GOTO Pen_select_idle
2833 P1:PEN 1
2834   GOTO Pen_return
2835 P2:PEN 2
2836   GOTO Pen_return
2837 P3:PEN 3
2838   GOTO Pen_return
2839 P4:PEN 4
2840   GOTO Pen_return
2841 P5:PEN 5
2842   GOTO Pen_return
2843 P6:PEN 6
2844 Pen_return:!
2845   KEY LABELS OFF
2846   RETURN
2847 Dumper:!********************************** DUMPER **************
2848   KEY LABELS OFF
2849   DUMP DEVICE IS 701
2850   OUTPUT KBD;"N";
2851   GOTO Main_menu
```

```
2879 File_err: !*************************** FILE_ERR ********************
2880  PRINTER IS 1
2881  PRINT USING "@,#"
2882  BEEP 2000,.3
2883  IF ERRN=70 OR ERRN=85 THEN
2884    PRINT "WARNING you  are initializing this disc. All data will be erased.
"
2885    INPUT "Hit <RETURN> to continue",Which$
2886    INITIALIZE ":CS80,700,1"
2887  END IF
2888  PRINT "Error in file name selection",ERRN,ERRM$
2889  GOTO Data_save
2890 Plot_set_up: !***************************** PLOT_SET_UP **************
2891  PRINTER IS 1
2892  OFF KEY
2893  PRINT "Do you want to use the Plotter?"
2894  GOSUB Yes_no
2895  OUTPUT KBD;"K";
2896  IF Answer$="Y" THEN INPUT "Put paper in the plotter then hit <RETURN>",Whi
ch$
2897  GINIT
2898  GRAPHICS ON
2899  IF Answer$="Y" THEN
2900    PLOTTER IS 705,"HPGL"
2901    VIEWPORT 0,125,0,100
2902    Which_pltr$="Plotter"
2903    Penn$="Axes"
2904    GOSUB Pen_select
2905  ELSE
2906    PLOTTER IS CRT,"INTERNAL"
2907    Which_pltr$="CRT"
2908    VIEWPORT 0,120,26,100
2909  END IF
2910  Load_ran=Load_max-Load_min
2911  T_ran=T_end-T_start
2912  WINDOW T_start-.1*(T_ran),T_end,Load_min-.1*Load_ran,Load_max+.13*Load_ran
2913  CLIP T_start,T_end,Load_min,Load_max
2914  GRID T_ran/10,Load_ran/10,T_start,Load_min,1,1
2915  CLIP OFF
```

```
2916  CSIZE 3
2917  LORG 4
2918  MOVE (T_start+T_end)/2,Load_max+.08*Load_ran
2919  LABEL USING "K";Sample_nr$&"  "&VAL$(Test_temp)&" C"
2920  LORG 6
2921  FOR I=T_start TO T_end STEP (T_start-T_end)/(-5)
2922    MOVE I,Load_min-.025*Load_ran
2923    LABEL USING "K";I
2924  NEXT I
2925  MOVE .5*(T_start+T_end),Load_min-.07*Load_ran
2926  LABEL USING "K";X_axis$
2927  LORG 8
2928  FOR I=Load_min TO Load_max STEP Load_ran/10
2929    MOVE T_start-(.01*(T_     T_start)),I
2930    LABEL USING "K";I
2931  NEXT I
2932  LORG 4
2933  MOVE T_start-(.07*(T_end-T_start)),Load_ran/2+Load_min
2934  DEG
2935  LDIR 90
2936  LABEL USING "K";Y_axis$
2937  LDIR 0
2938  LORG 4
2939  IF Extensometer$="On" THEN
2940    Exp_ran=Explotmax-Explot0
2941    CLIP T_start+.1*T_ran,T_end,Load_max,Load_max+.1*Load_ran
2942    AXES T_ran/10,Load_ran/20,T_start,Load_max
2943    CLIP OFF
2944    FOR I=T_start TO T_end STEP T_ran/10
2945      MOVE I,Load_max+Load_ran*.03
2946      LABEL USING "K";(I-Exp_int)/Exp_con
2947    NEXT I
2948  END IF
2949  RETURN
2950 Which_msu: !************************** WHICH_MSU ****************
2951  OFF KEY
2952  MASS STORAGE IS ":CS80,700,0"!        HARD DRIVE FOR 2732A25753
2953  !                                      OR FLOPPY FOR 2702A21048
2954  CLEAR SCREEN
2955  PRINT "Do you want to store/recall data to/from the HARD DRIVE or 3-1/2 FL
OPPY?"
2956  PRINT " "
2957  PRINT "***<YES>   FOR HARD DRIVE                    <NO> FOR FLOPPY*****"
2958  GOSUB Yes_no
2959  IF Answer$="Y" THEN GOTO Hard_msu
2960  CLEAR SCREEN
2961  PRINT "Which HP system are you using?       (CODES ARE MACHINE DEPENDENT)"
2962  PRINT " "
2963  PRINT "***<YES> IF MSU #1 IN THE INSTRON ROOM,      <NO> FOR MSU #2*****"
2964  PRINT "          (SERIAL # 2732A25753)              (SERIAL # 2702A21048)
"
```

```
2879 File_err: !************************** FILE_ERR ******************
2880  PRINTER IS 1
2881  PRINT USING "@,#"
2882  BEEP 2000,.3
2883  IF ERRN=78 OR ERRN=85 THEN
2884    PRINT "WARNING you  are initializing this disc. All data will be erased.
"
2885    INPUT "Hit <RETURN> to continue",Which$
2886    INITIALIZE ":CS80,700,1"
2887  END IF
2888  PRINT "Error in file name selection",ERRN,ERRM$
2889  GOTO Data_save
2890 Plot_set_up: !**************************** PLOT_SET_UP *************
2891  PRINTER IS 1
2892  OFF KEY
2893  PRINT "Do you want to use the Plotter?"
2894  GOSUB Yes_no
2895  OUTPUT KBD;"K";
2896  IF Answer$="Y" THEN INPUT "Put paper in the plotter then hit <RETURN>",Whi
ch$
2897  GINIT
2898  GRAPHICS ON
2899  IF Answer$="Y" THEN
2900    PLOTTER IS 705,"HPGL"
2901    VIEWPORT 0,125,0,100
2902    Which_pltr$="Plotter"
2903    Penn$="Axes"
2904    GOSUB Pen_select
2905  ELSE
2906    PLOTTER IS CRT,"INTERNAL"
2907    Which_pltr$="CRT"
2908    VIEWPORT 0,120,26,100
2909  END IF
2910  Load_ran=Load_max-Load_min
2911  T_ran=T_end-T_start
2912  WINDOW T_start-.1*(T_ran),T_end,Load_min-.1*Load_ran,Load_max+.13*Load_ran
2913  CLIP T_start,T_end,Load_min,Load_max
2914  GRID T_ran/10,Load_ran/10,T_start,Load_min,1,1
2915  CLIP OFF
2916  CSIZE 3
2917  LORG 4
2918  MOVE (T_start+T_end)/2,Load_max+.08*Load_ran
2919  LABEL USING "K";Sample_nr$&"  "&VAL$(Test_temp)&" C"
2920  LORG 6
2921  FOR I=T_start TO T_end STEP (T_start-T_end)/(-5)
2922    MOVE I,Load_min-.025*Load_ran
2923    LABEL USING "K";I
2924  NEXT I
2925  MOVE .5*(T_start+T_end),Load_min-.07*Load_ran
2926  LABEL USING "K";X_axis$
2927  LORG 8
```

```
2928  FOR I=Load_min TO Load_max STEP Load_ran/10
2929    MOVE T_start-(.01*(T_end-T_start)),I
2930    LABEL USING "K";I
2931  NEXT I
2932  LORG 4
2933  MOVE T_start-(.07*(T_end-T_start)),Load_ran/2+Load_min
2934  DEG
2935  LDIR 90
2936  LABEL USING "K";Y_axis$
2937  LDIR 0
2938  LORG 4
2939  IF Extensometer$="On" THEN
2940    Exp_ran=Explotmax-Explot0
2941    CLIP T_start+.1*T_ran,T_end,Load_max,Load_max+.1*Load_ran
2942    AXES T_ran/10,Load_ran/20,T_start,Load_max
2943    CLIP OFF
2944    FOR I=T_start TO T_end STEP T_ran/10
2945      MOVE I,Load_max+Load_ran*.03
2946      LABEL USING "K";(I-Exp_int)/Exp_con
2947    NEXT I
2948  END IF
2949  RETURN
2950 Which_msu: !*********************** WHICH_MSU ****************
2951  OFF KEY
2952  MASS STORAGE IS ":CS80,700,0"!         HARD DRIVE FOR 2732A25753
2953  !                                       OR FLOPPY FOR 2702A21048
2954  CLEAR SCREEN
2955  PRINT "Do you want to store/recall data to/from the HARD DRIVE or 3-1/2 FL
OPPY?"
2956  PRINT " "
2957  PRINT "***<YES>   FOR HARD DRIVE                    <NO> FOR FLOPPY*****"
2958  GOSUB Yes_no
2959  IF Answer$="Y" THEN GOTO Hard_msu
2960  CLEAR SCREEN
2961  PRINT "Which HP system are you using?       (CODES ARE MACHINE DEPENDENT)"
2962  PRINT " "
2963  PRINT "***<YES> IF MSU #1 IN THE INSTRON ROOM,        <NO> FOR MSU #2*****"
2964  PRINT "           (SERIAL # 2732A25753)                (SERIAL # 2702A21048)
"
2965  GOSUB Yes_no
2966  IF Answer$="Y" THEN MASS STORAGE IS ":CS80,700,0"
2967  IF Answer$="N" THEN MASS STORAGE IS ":CS80,700,1"
2968  KEY LABELS OFF
2969  RETURN
2970 Hard_msu: !
2971  CLEAR SCREEN
2972  PRINT "Which HP system are you using?       (CODES ARE MACHINE DEPENDENT)"
2973  PRINT " "
2974  PRINT "***<YES> IF MSU #1 IN THE INSTRON ROOM,        <NO> FOR MSU #2*****"
2975  GOSUB Yes_no
2976  IF Answer$="Y" THEN MASS STORAGE IS ":CS80,700,1"
```

```
2977  IF Answer$="N" THEN MASS STORAGE IS ":CS80,700,0"
2978  KEY LABELS OFF
2979  RETURN
2980 Yes_no: !
2981  OFF KEY
2982  KEY LABELS OFF
2983  FOR Q=1 TO 4
2984    ON KEY Q LABEL "YES" GOTO Yess
2985    ON KEY Q+4 LABEL "NO" GOTO Noo
2986  NEXT Q
2987  KEY LABELS ON
2988 Yes_no_idle:GOTO Yes_no_idle
2989 Yess:Answer$="Y"
2990  RETURN
2991 Noo:Answer$="N"
2992  RETURN
2993 Analyze_data: !
2994  PRINTER IS 1
2995  PRINT "Data analysis section not written yet"
2996  BEEP
2997  GOTO Main_menu
2998 Data_red_menu:   !
2999 ! THIS SECTION IS FOR MAKING A "CORRECTED" TRUE/ENGR STRESS-
3000 ! STRAIN CURVES -------- DATA REDUCTION ---------
3001  OFF KEY
3002  ON KEY 1 LABEL " INPUT    TYPE  " GOTO Input_type!
3003  ON KEY 2 LABEL " SLOPE    OKAY? " GOTO Slope_ok!
3004  ON KEY 3 LABEL "  PLOT    ENGR  " GOTO Corr_engr!
3005  ON KEY 4 LABEL "  PLOT    TRUE  " GOTO Corr_true!
3006  ON KEY 5 LABEL "  FILE    DATA  " GOTO Data_save2!
3007  ON KEY 6 LABEL "  MORE   CURVES?" GOTO More_plots!
3008  ON KEY 7 LABEL "  MAIN     MENU " GOTO Main_menu!
3009  ON KEY 8 LABEL "  MAIN     MENU " GOTO Main_menu!
3010  KEY LABELS ON
3011 Data_red_idle:GOTO Data_red_idle
3012 Slope_ok:!************************ SLOPE_OK *****************
3013  GOSUB Yes_no
3014  IF Answer$="Y" THEN GOTO Data_red_menu!CHANGE TO CORR_ENGR???
3015  IF Answer$="N" THEN GOSUB Plot_data
3016 Input_type:!******************** INPUT_TYPE *****************
3017  PRINTER IS 1
3018  PRINT "Select method of designating the points to calculate the slope"
3019  ON KEY 1 LABEL "Mouse" GOTO Mouse_pts     !
3020  ON KEY 2 LABEL "Mouse" GOTO Mouse_pts!
3021  ON KEY 3 LABEL "Cursor  Keys" GOTO Cursor_pts!
3022  ON KEY 4 LABEL "Cursor  Keys" GOTO Cursor_pts!
3023  ON KEY 5 LABEL "X-Y     inputs" GOTO Xy_pts!
3024  ON KEY 6 LABEL "X-Y     inputs" GOTO Xy_pts!
3025  ON KEY 7 LABEL "OTHER" GOTO Cursor_pts!
3026  ON KEY 8 LABEL "OTHER" GOTO Cursor_pts!
3027 Desig_idle:GOTO Desig_idle
```

```
3028 Mouse_pts:! Uses Mouse to designate points to calculate slope
3029 ! Fill in lines to use Mouse later
3030  GOTO Solve_slope
3031 Cursor_pts:! Uses Cursor to designate points to calculate slope
3032  KEY LABELS OFF
3033  TRACK 3 IS ON!   initializes cursor routine
3034  GRAPHICS INPUT IS KBD,"ARROW KEYS"!  specifies the input device
3035  SET LOCATOR Scale_c,(Hi_y+Low_y)/2!   initializes location of cursor
3036  FOR Q=1 TO 4
3037    ON KEY Q LABEL "Point 1 Baseline" GOTO Locator_spin
3038    ON KEY Q+4 LABEL "<RETURN>when loc" GOTO Locator_spin
3039  NEXT Q
3040  KEY LABELS ON
3041 Locator_spin: !
3042    RG 5
3043    ITIZE T1,L1!        location of cursor when <RETURN> pressed
3044    E T1,L1!        places "*" on location & beeps to let you
3045    BEL USING "K";"*"
3046  BEEP 2000,.1
3047  FOR Q=1 TO 4
3048    ON KEY Q LABEL "Point 2 Baseline" GOTO Locator_spin2
3049    ON KEY Q+4 LABEL "<RETURN>when loc" GOTO Locator_spin2
3050  NEXT Q
3051  KEY LABELS ON
3052 Locator_spin2: !
3053  LORG 5
3054  DIGITIZE T2,L2!        location of cursor when <RETURN> pressed
3055  MOVE T2,L2!        places "@" on location & beeps to let you
3056  LABEL USING "K";"@"
3057  BEEP 2000,.2
3058  BEEP 2000,.1
3059  FOR Q=1 TO 4
3060    ON KEY Q LABEL "CUTOFF   POINT  " GOTO Locator_spin3
3061    ON KEY Q+4 LABEL "<RETURN>when loc" GOTO Locator_spin3
3062  NEXT Q
3063  KEY LABELS ON
3064 Locator_spin3: !
3065  LORG 5
3066  DIGITIZE T9,L9!                    THIS IS END OF GOOD DATA
3067  MOVE T9,L9
3068  LABEL USING "K";"#"
3069  BEEP 2000,.2
3070  BEEP 2000,.1
3071  GOTO Slope_solve
3072 Xy_pts:! Uses TIME-LOAD data to designate points to calculate slope
3073  INPUT "WHAT IS COORD FOR FIRST POINT (X1,Y1)?",T1,L1
3074  INPUT "WHAT IS COORD FOR 2nd POINT (X2,Y2)?",T2,L2
3075  INPUT "WHAT IS LAST GOOD DATA POINT (JUST THE TIME ONLY)?",T9
3076  GOTO Slope_solve
3077 Slope_solve:! Solves eqn of line y=Mx+b; y--> LOAD  x--> Time
3078  Slope=(L2-L1)/(T2-T1)!       Solves for slope M
3079  P0=L2-(Slope*T2)!            Solves for y-intercept
```

```
3080  T0=-P0/Slope!                         Solves for X-intercept
3081 !    Y  =   M     (X)    +  B
3082 !    P  = SLOPE (TIME) +  P0
3083  GOTO Slope_draw
3084 Slope_draw:! Draws line y=Mx+b on top of LOAD-TIME curve
3085  LINE TYPE 1
3086  MOVE T0,0
3087  LORG 5
3088  LABEL USING "K";"*"
3089  DRAW T0,0
3090  DRAW ((1.5*L2-P0)/Slope),1.5*L2
3091  LINE TYPE 1
3092  GOTO Data_red_menu
3093 Corr_engr:!************** CORR_ENGR ***********************************
3094  PRINT "Do you want an TRUE or ENGR stress vs strain plot?"
3095  PRINT "***<YES>  FOR TRUE STRESS/STRAIN        <NO> ENGR STRESS/STRAIN"
3096  GOSUB Yes_no
3097  IF Answer$="Y" THEN GOTO Corr_true
3098  Ee=2
3099  GOTO Flag_engr!
3100  BEEP
3101 Corr_true:! *********************** CORR_TRUE *******************
3102  Xx=3!                    THIS MEANS TRUE STRESS/STRAIN AXES LABELS TO PLOT
3103  Ee=3
3104 Flag_engr: !
3105  IF Ee=2 THEN Xx=2!       THIS MEANS ENGR STRESS/STRAIN AXES LABELS TO PLOT
3106  Xhead_spd=Str_rate
3107  BEEP
3108  PRINT " "
3109  PRINT "                  CALCULATIONS IN PROGRESS - PLEASE WAIT FOR BEEP!!"
3110  Tel=0
3111  Delta_time=0
3112  Displ=0
3113  Strain_max=0
3114  Stress_max=0
3115  Tt0=INT(T0)
3116  FOR I=Tt0 TO 5000!                       PRIOR TO T0 WILL BE ZEROS
3117    Tp=Strain(I)
3118    Pp=Stress(I)
3119    IF Tp>T9 THEN GOTO Flag_one!       END OF GOOD DATA
3120    Tel=(Pp-P0)/Slope
3121    Delta_time=Tp-Tel
3122    Displ=Delta_time*Xhead_spd
3123    Stress_engr(I)=(1000*Pp)/Sample_area!   KILO TO CHANGE KN TO MPa
3124    Strain_engr(I)=Displ/Gauge
3125    IF Strain_engr(I)>Strain_max THEN Strain_max=Strain_engr(I)
3126    IF Stress_engr(I)>Stress_max THEN Stress_max=Stress_engr(I)
3127    Stress(I)=Stress_engr(I)*(1+Strain_engr(I))!       THIS IS REALLY
3128    Strain(I)=LOG(1+Strain_engr(I))!                 TRUE STRESS & STRAIN
3129    IF Strain(I)<0 THEN Strain(I)=0
```

```
3131    !IF Strain(I)>Strain_max THEN Strain_max=Strain(I)
3132    !IF Stress(I)>Stress_max THEN Stress_max=Stress(I)
3133    Zz=I
3134    Zzz=5000-Zz
3135       IF Zzz=5000 OR Zzz=4000 OR Zzz=3000 OR Zzz=2000 OR Zzz=1000 THEN
3136    PRINT Zzz!                         COUNT DOWN - TELLS HOW LONG UNTIL DONE
3137    END IF
3138  NEXT I
3139  Zzzz=7!                                   TELLS THE MAX VALUE FOR AXES
3140 !Flag_one: !
3141  BEEP
3142  !T_end=Strain_max*1.2                                  GIVES STRANGE
3143  !Load_max=Stress_max*1.2                               UNITS ON AXES
3144  GOSUB Plot_data
3145  PRINT " DO YOU WISH TO SAVE THIS PLOT EITHER ON DISK OR HARD DRIVE?"
3146  PRINT "                            <YES>              <NO>"
3147  GOTO Yes_no
3148  IF Answer$="Y" THEN GOSUB Data_save2
3149 More_plots: !
3150  PRINT " DO YOU WISH TO ANOTHER PLOT SUPERIMPOSED ON THIS PLOT?"
3151  PRINT "                     -------      ------------"
3152  PRINT "                            <YES>              <NO>"
3153  GOTO Yes_no
3154  IF Answer$="Y" THEN
3155     Old_axes=3! ************USE SAME AXES WHEN PLOTTING
3156     GOSUB Re_data
3157     GOSUB Plot_data_2
3158  END IF
3159  PRINT " DO YOU WISH TO A SEPERATE, NEW PLOT?"
3160  PRINT "                       --------  ---"
3161  PRINT "                            <YES>              <NO>"
3162  GOTO Yes_no
3163  IF Answer$="Y" THEN
3164     Old_axes=2! ***********USE NEW AXES WHEN PLOTTING
3165     GOSUB Plot_data
3166  END IF
3167  IF Answer$="N" THEN GOTO Data_red_menu
3168 Data_save2: !************************* DATA_SAVE2 **    ***********
3169  GOSUB Which_msu
3170  OFF KEY
3171  ON KEY 1 LABEL "STORE     DATA" GOTO Data_save2_1
3172  FOR Q=2 TO 7
3173    ON KEY Q LABEL " " GOTO Data_save2_idle
3174  NEXT Q
3175  ON KEY 8 LABEL "MAIN      MENU" GOTO Main_menu
3176  KEY LABELS ON
3177 Data_save2_idle:GOTO Data_save2_idle
3178 Data_save2_1: !*****************************DATA_SAVE2_1 *************
3179 !INPUT "File to be used? Don't type suffix B,C,orZ.",File_name$
3180  ON ERROR GOTO File_err
```

```
3181  7;;-7;*16
3182  !         NEED TO MAKE THIS FILE THE ENGR AND TRUE ALSO
3183    CREATE BDAT "E1",1,5000!       FILE FOR ENGR STRESS/STRAIN
3184    CREATE BDAT "E2",1,5000!    CHANGE FROM "E2" TO FILENAME&E2
3185    ASSIGN @Path1 TO "E1"
3186    ASSIGN @Path2 TO "E2"
3187    OUTPUT @Path1;Strain_engr(*)!     IT GETS STUCK HERE
3188    OUTPUT @Path2;Stress_engr(*)
3189    ASSIGN @Path1 TO *
3190    ASSIGN @Path2 TO *
3191    CREATE BDAT "T1",1,5000!        FILE FOR TRUE STRESS/STRAIN
3192    CREATE BDAT "T2",1,5000!  THIS WAS ADDED IN LATER?!?
3193    ASSIGN @Path1 TO "T1"!   IT SAVED A T1 FILE!!!!!!!
3194    ASSIGN @Path2 TO "T2"
3195    OUTPUT @Path1;Strain(*)
3196    OUTPUT @Path2;Stress(*)
3197    ASSIGN @Path1 TO *
3198    ASSIGN @Path2 TO *
3199  OFF ERROR
3200  GOTO Data_red_menu
3201  END
3202  SUB Changer(Ara(*),F)!*************  CHANGER *******************
3203    FOR I=1 TO 5000
3204      Ara(I)=Ara(I)*F
3205    NEXT I
```

APPENDIX B. TRUE STRESS VS. TRUE STRAIN CURVE

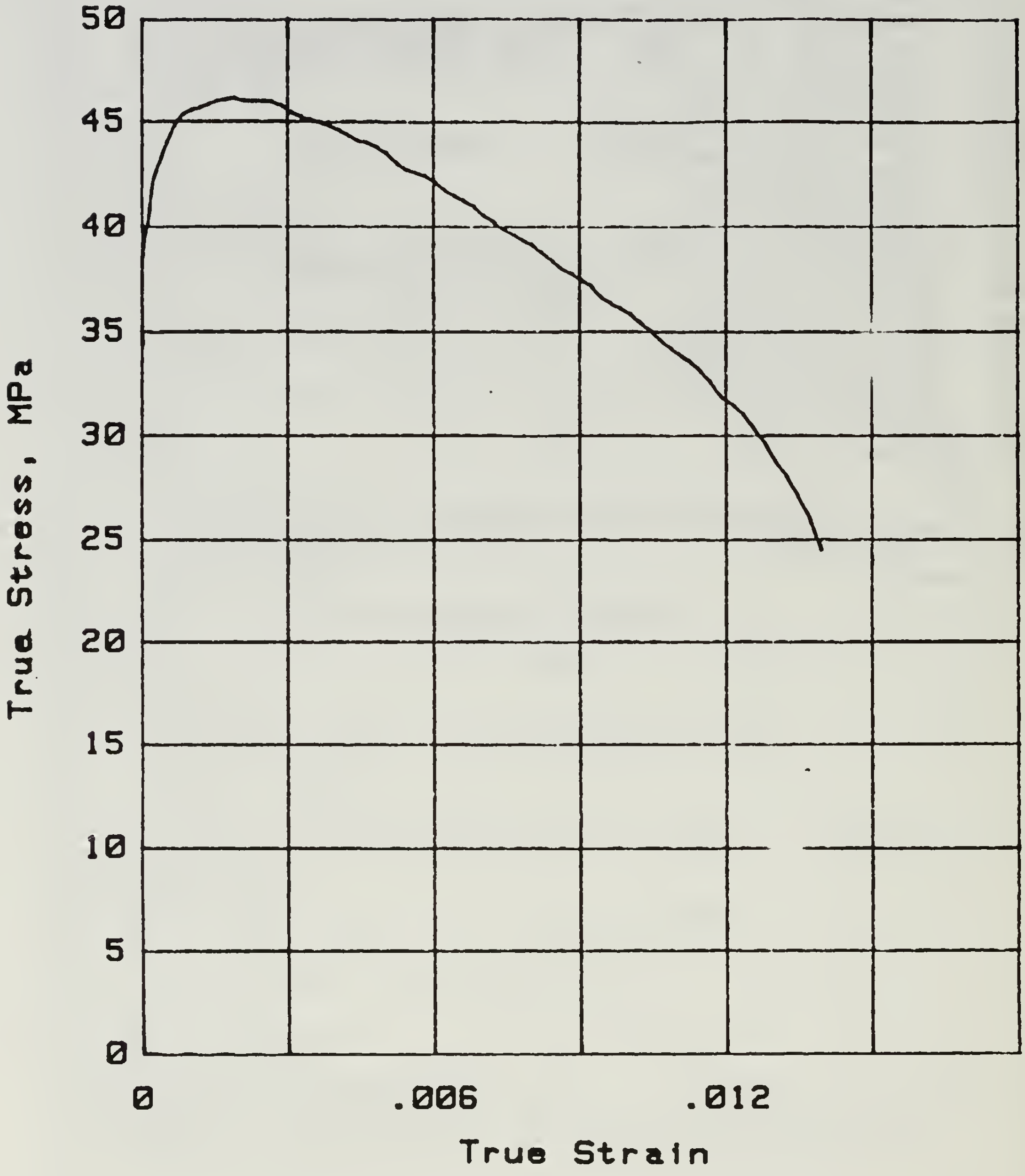

Figure 25. True stress vs. true strain, sample A, 10 vol. pct. Alumina, 400°C

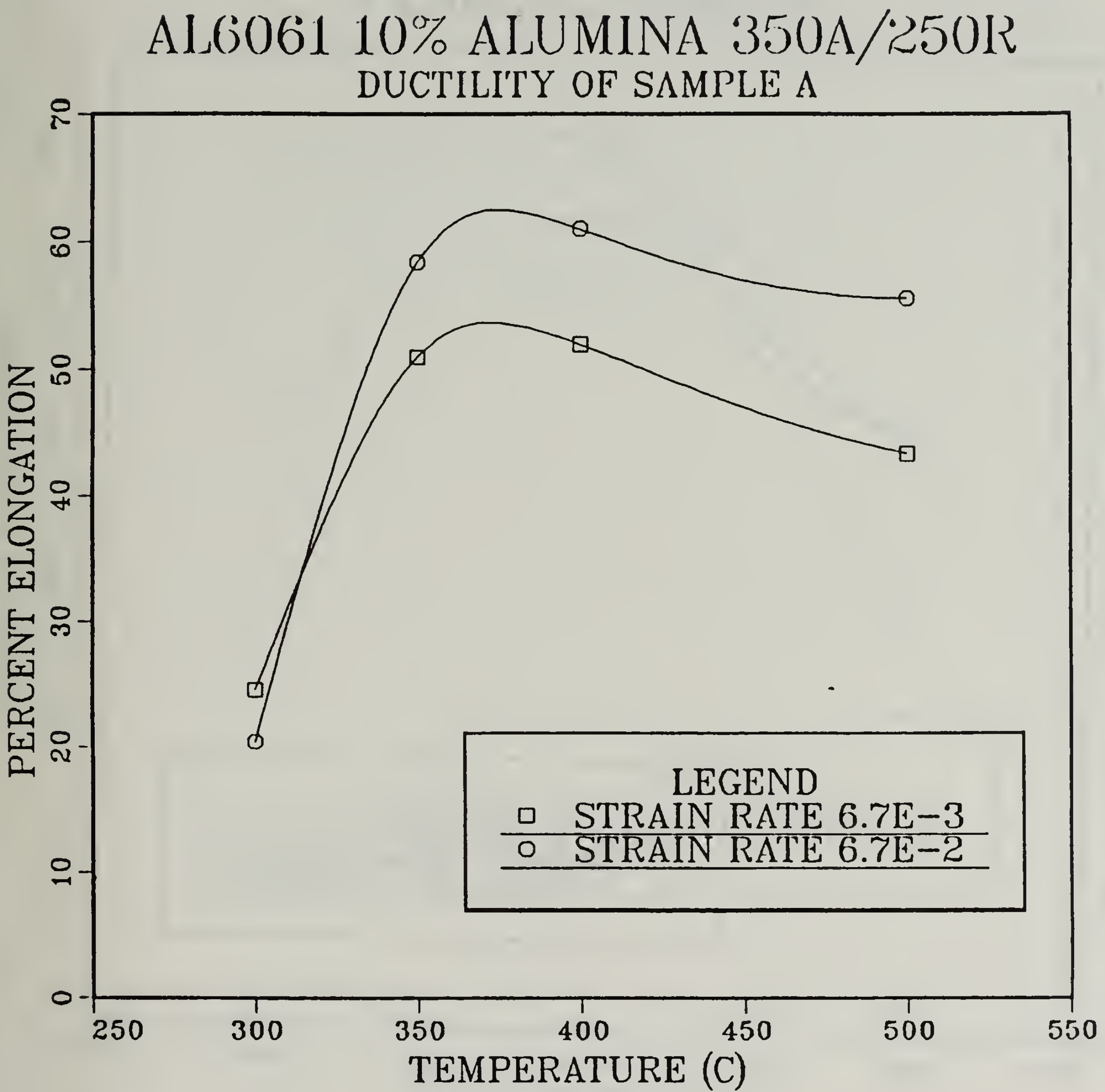

Figure 26. Ductility vs. temperature, sample A, 10 vol. pct. Alumina.

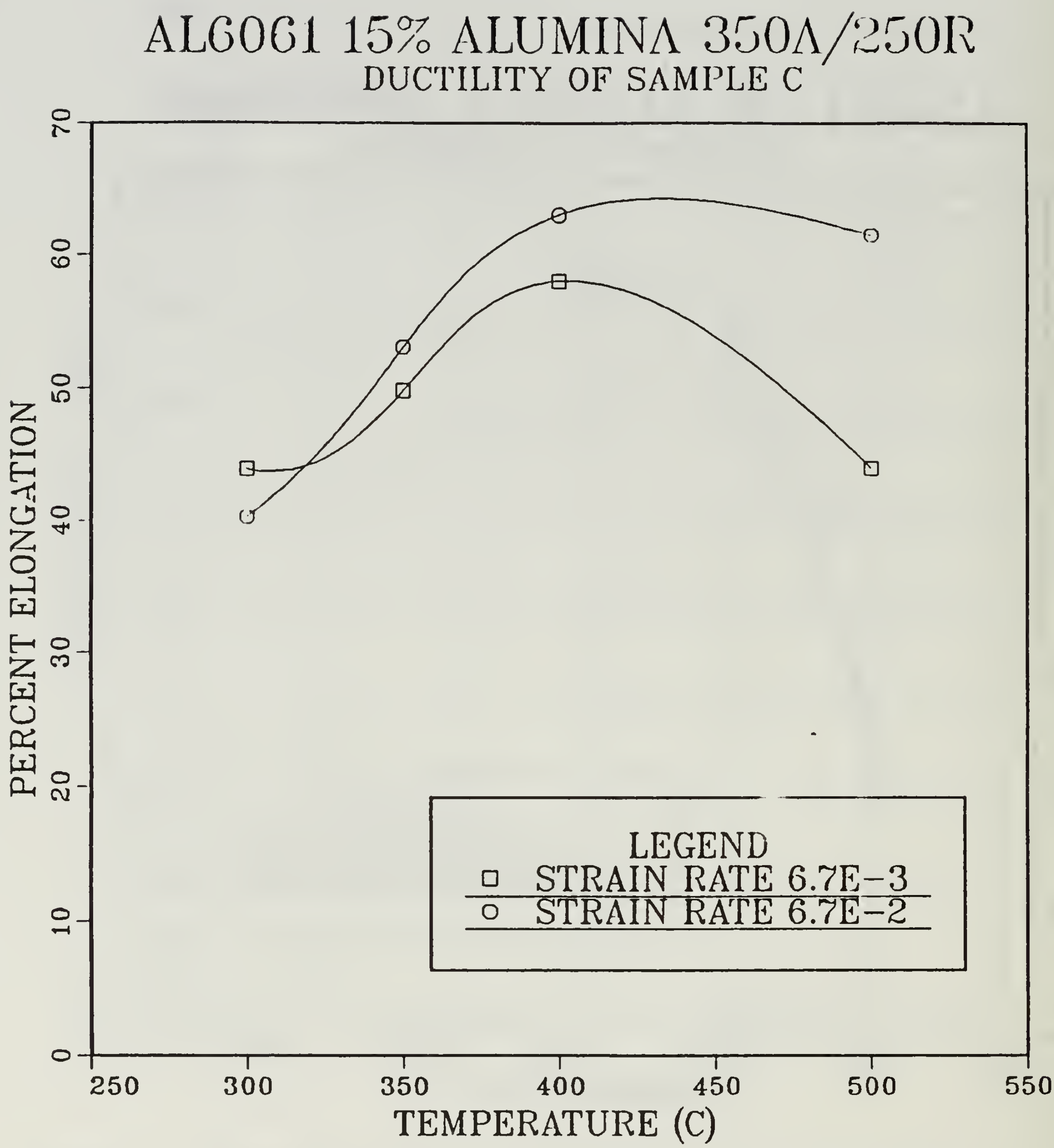

Figure 27. Ductility vs. temperature, sample C, 15 vol. pct. Alumina.

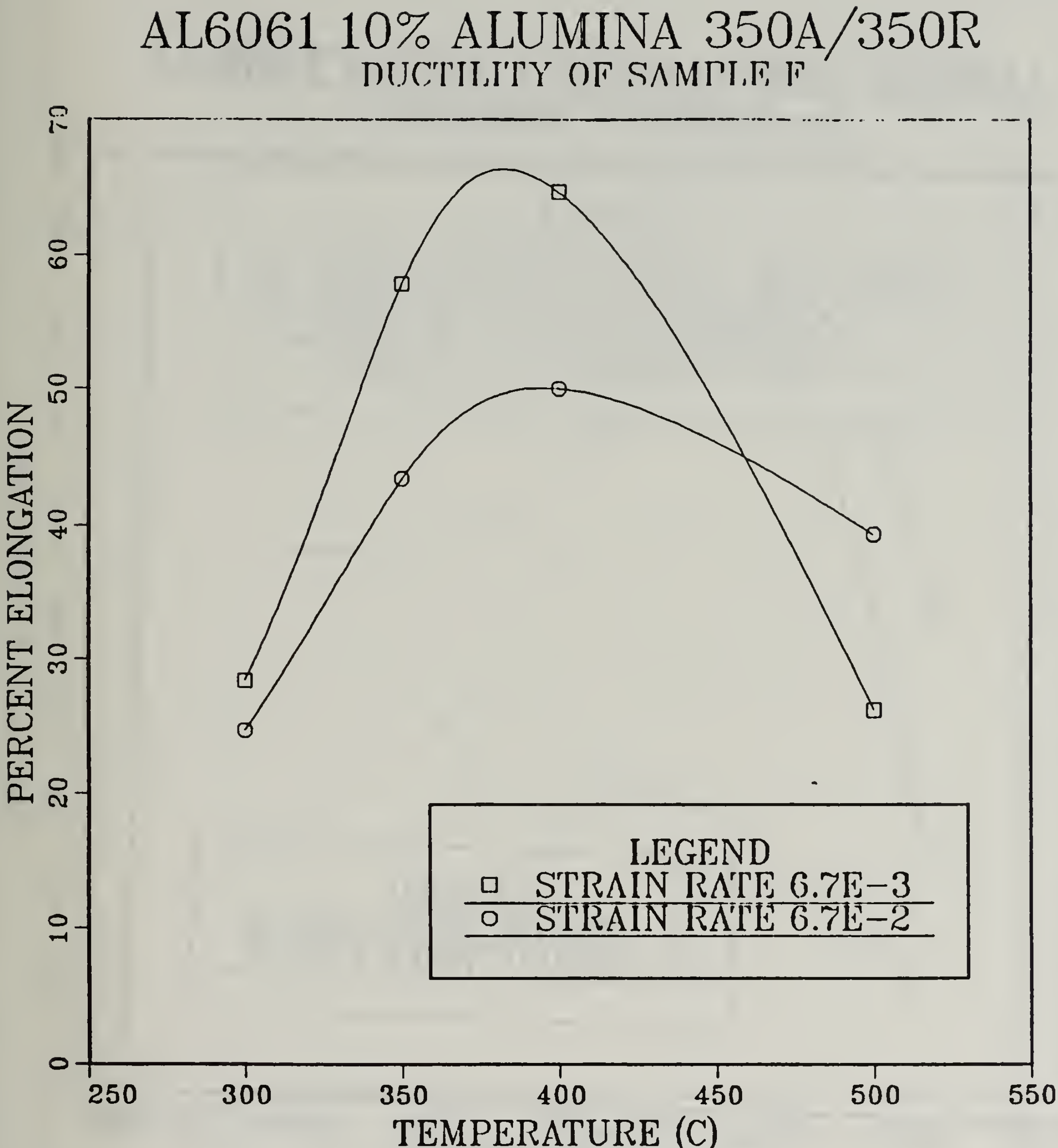

Figure 28. Ductility vs. temperature, sample F, 10 vol. pct. Alumina.

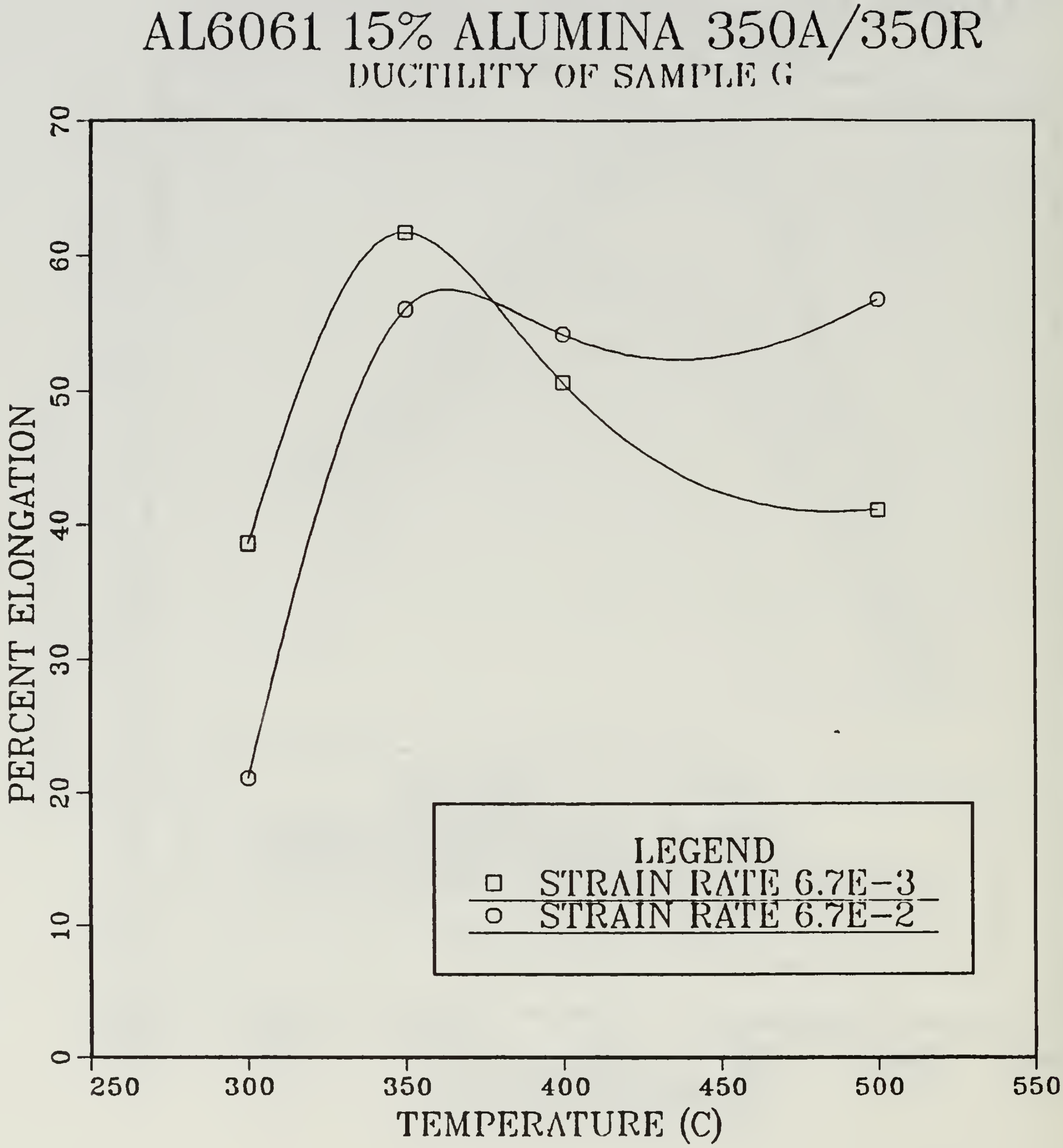

Figure 29. Ductility vs. temperature, sample G, 15 vol. pct. Alumina.

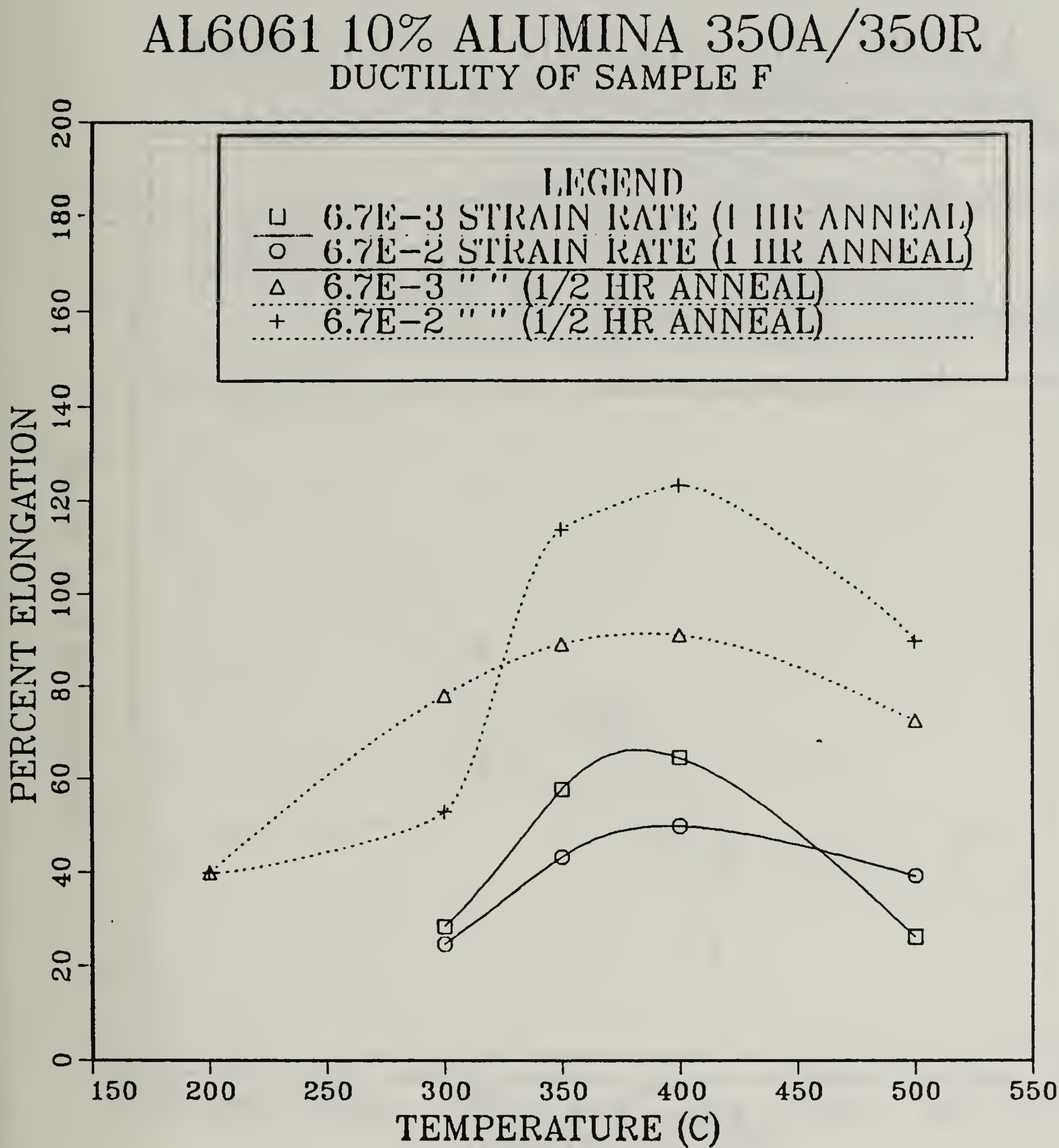

Figure 30. Ductility vs. temperature, sample F, 10 vol. pct. Alumina.

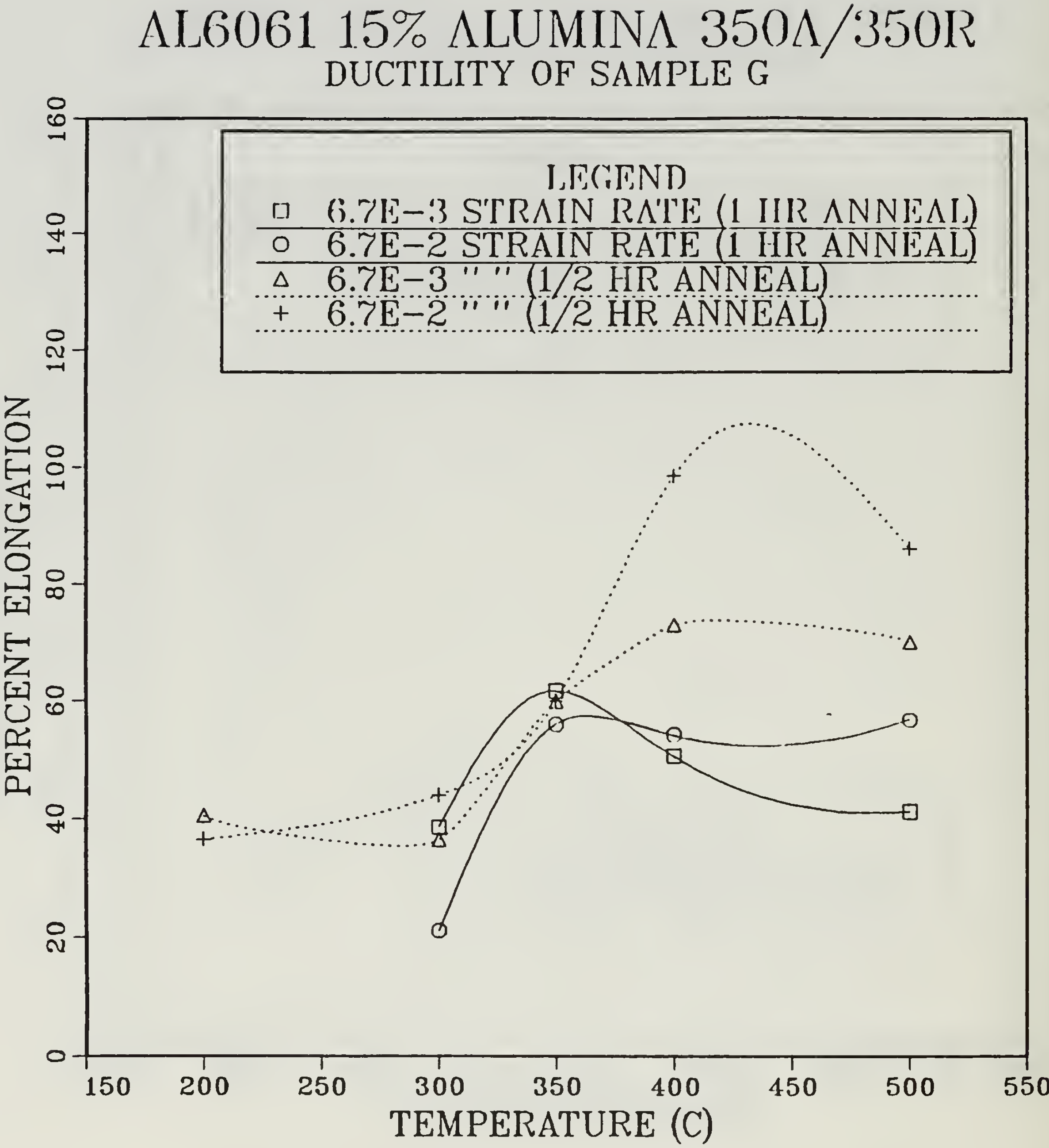

Figure 31. Ductility vs. temperature, sample G, 15 vol. pct. Alumina.

APPENDIX D. ULTIMATE STRENGTH VS. TEMPERATURE CURVES

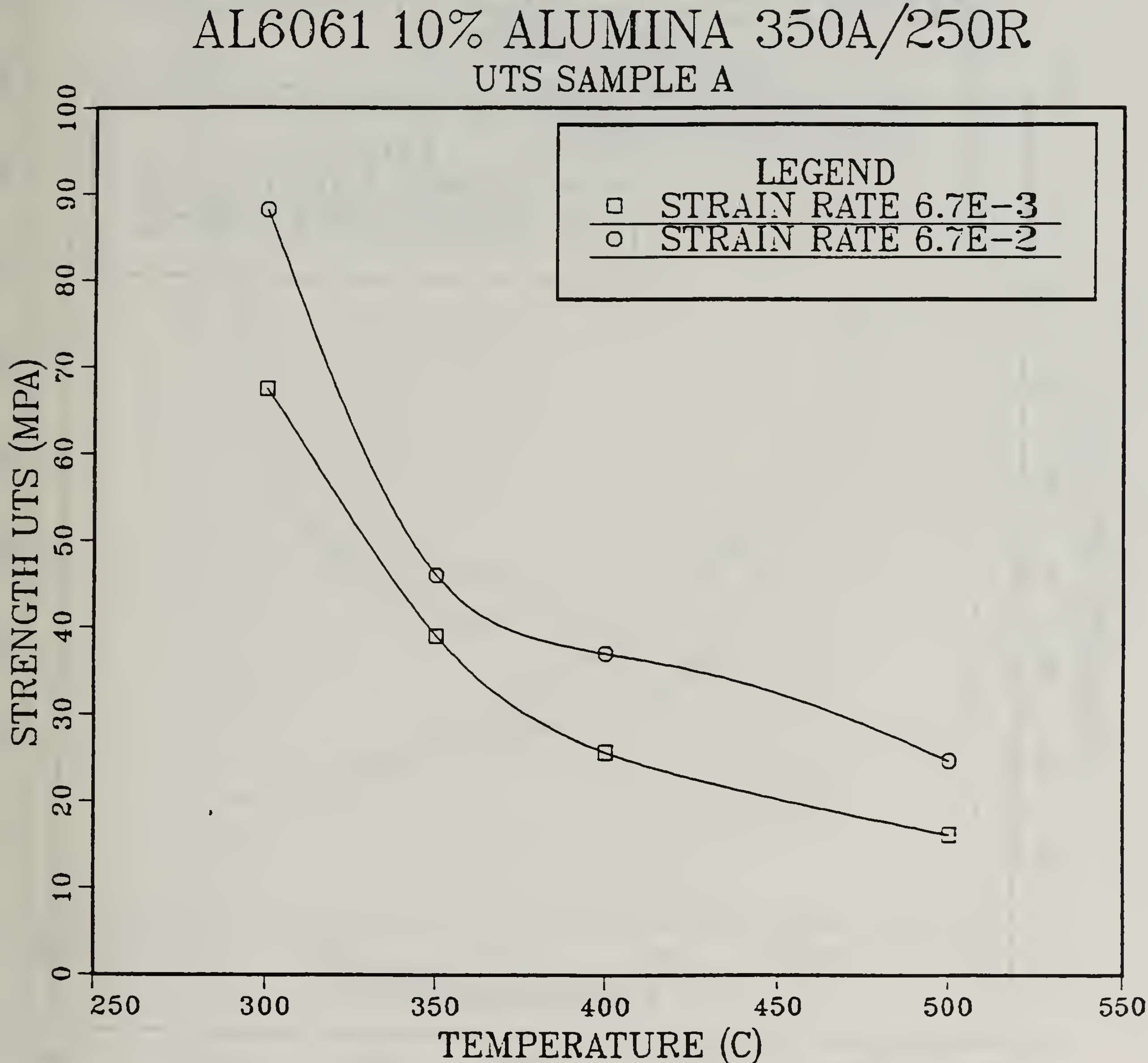

Figure 32. Ultimate strength vs. temperature, sample A, 10 vol. pct. Alumina.

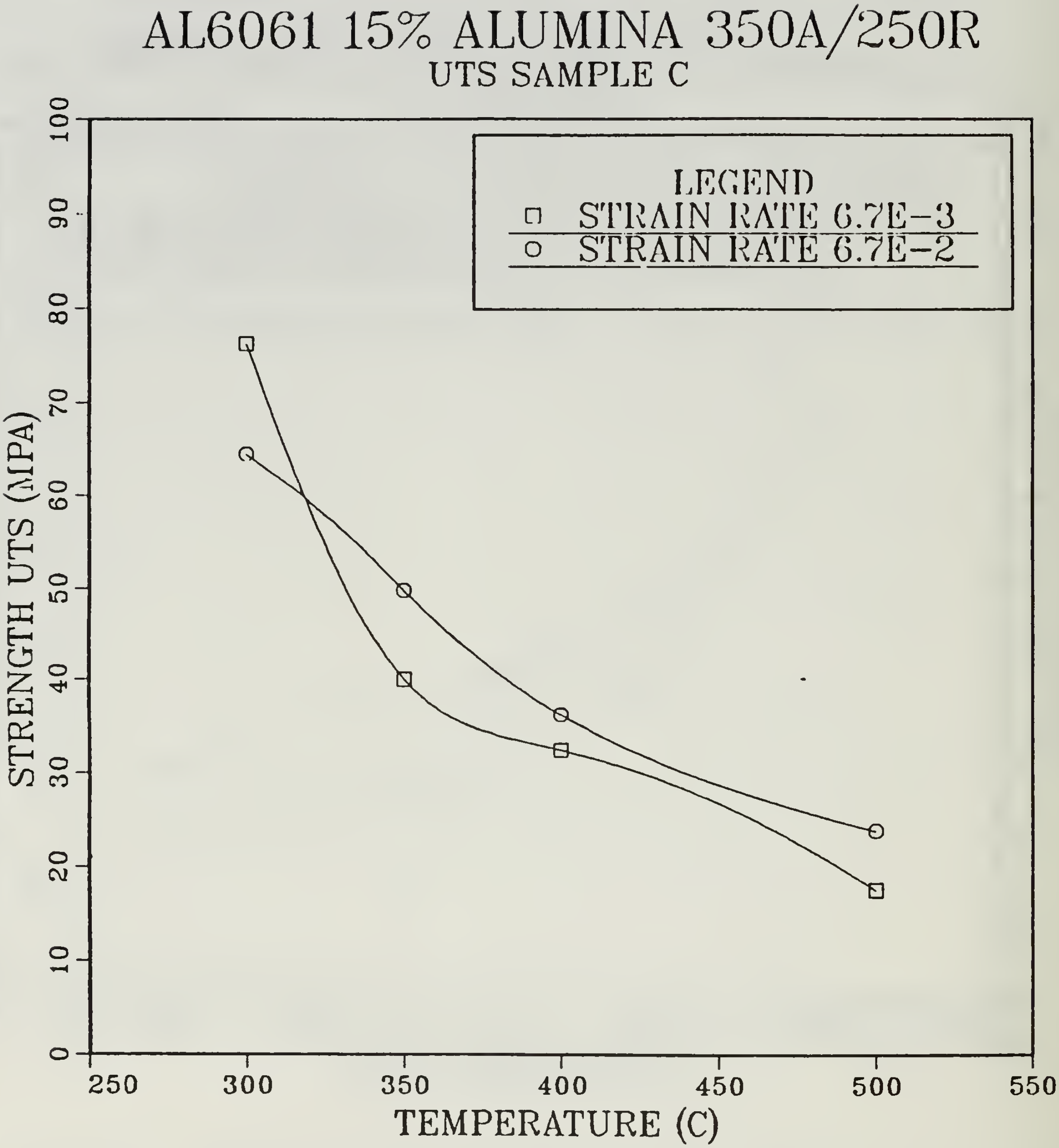

Figure 33. Ultimate strength vs. temperature, sample C, 15 vol. pct. Alumina.

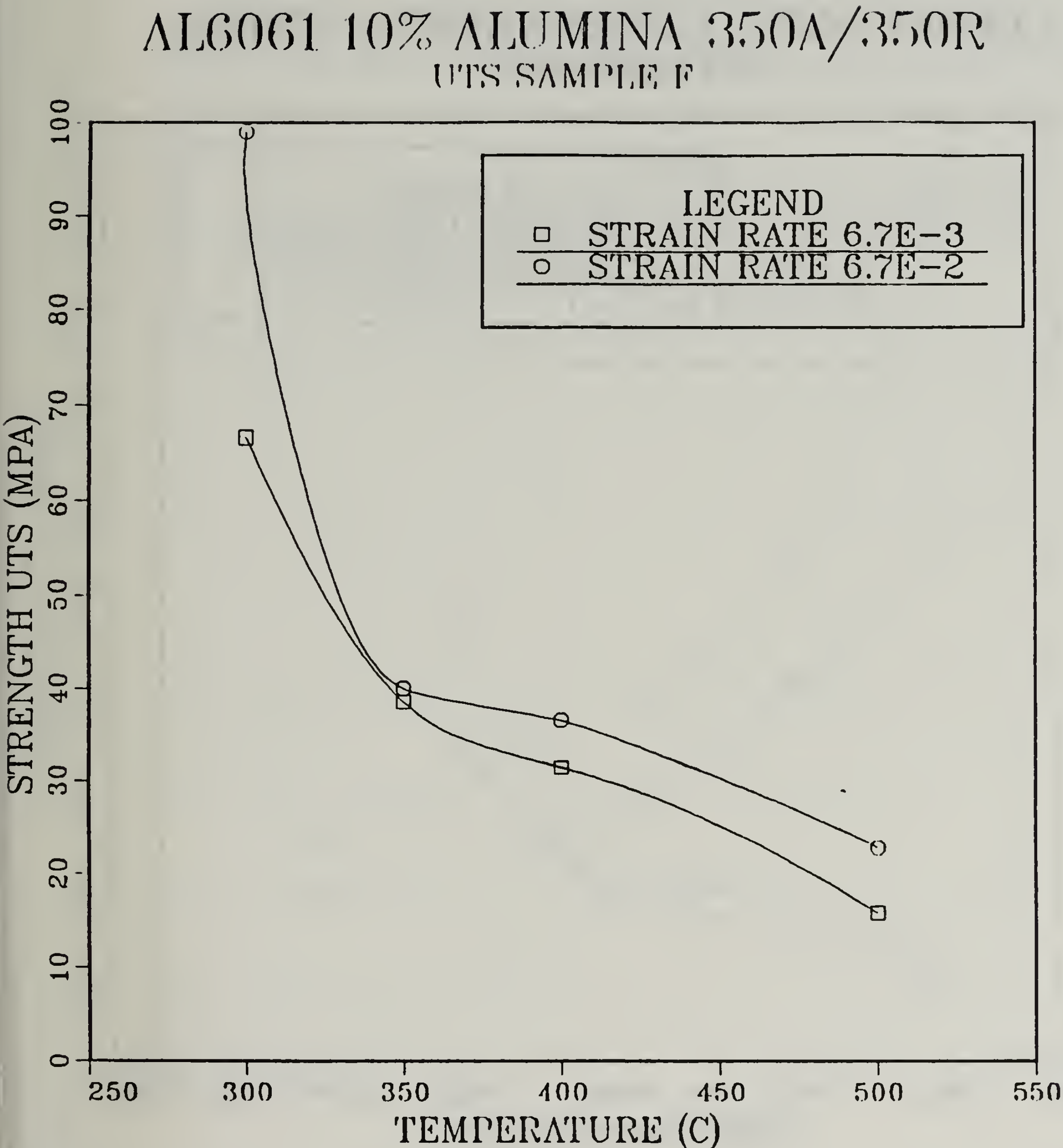

Figure 34. Ultimate strength vs. temperature, sample F, 10 vol. pct. Alumina.

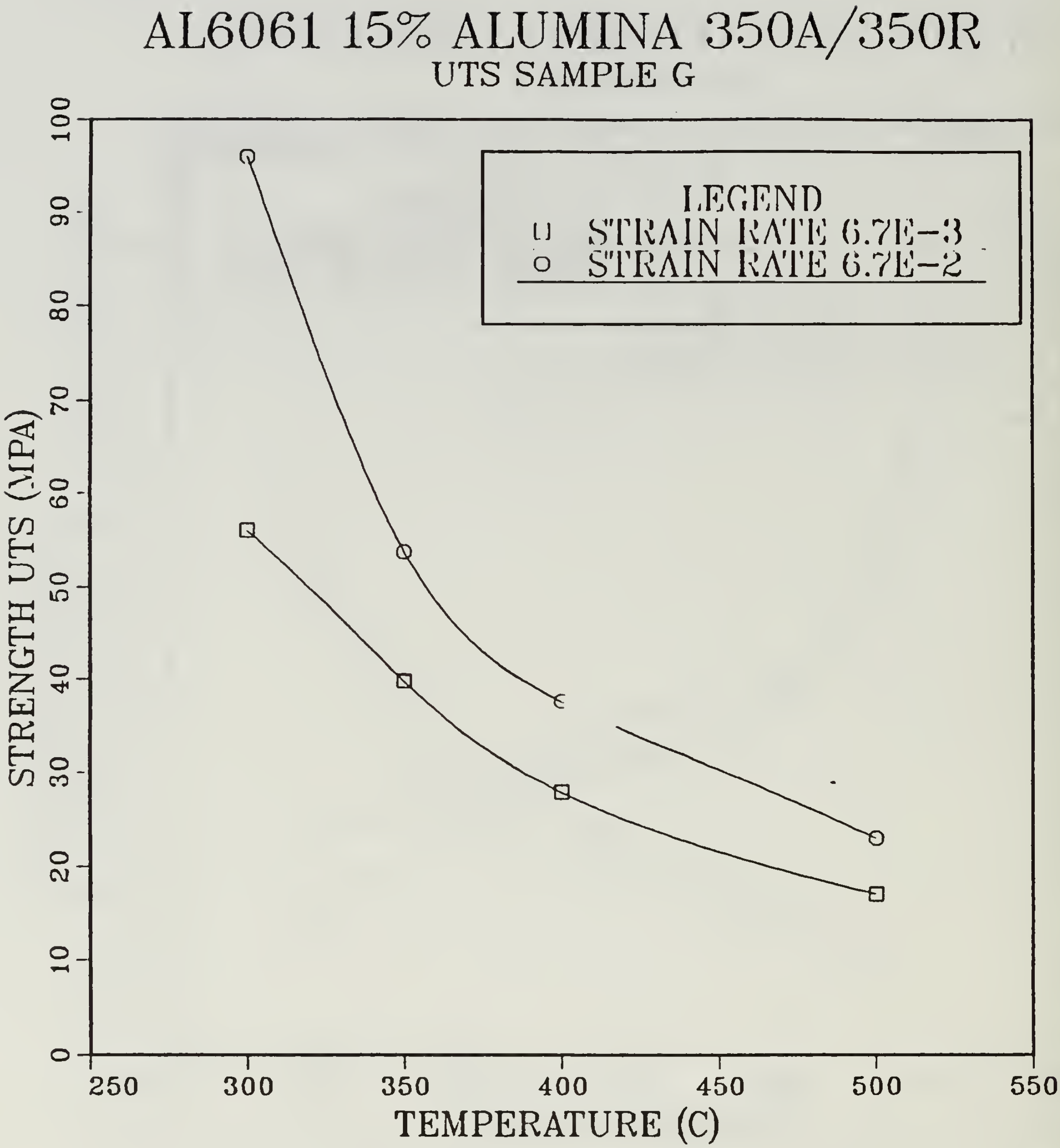

Figure 35. Ultimate strength vs. temperature, sample G, 15 vol. pct. Alumina.

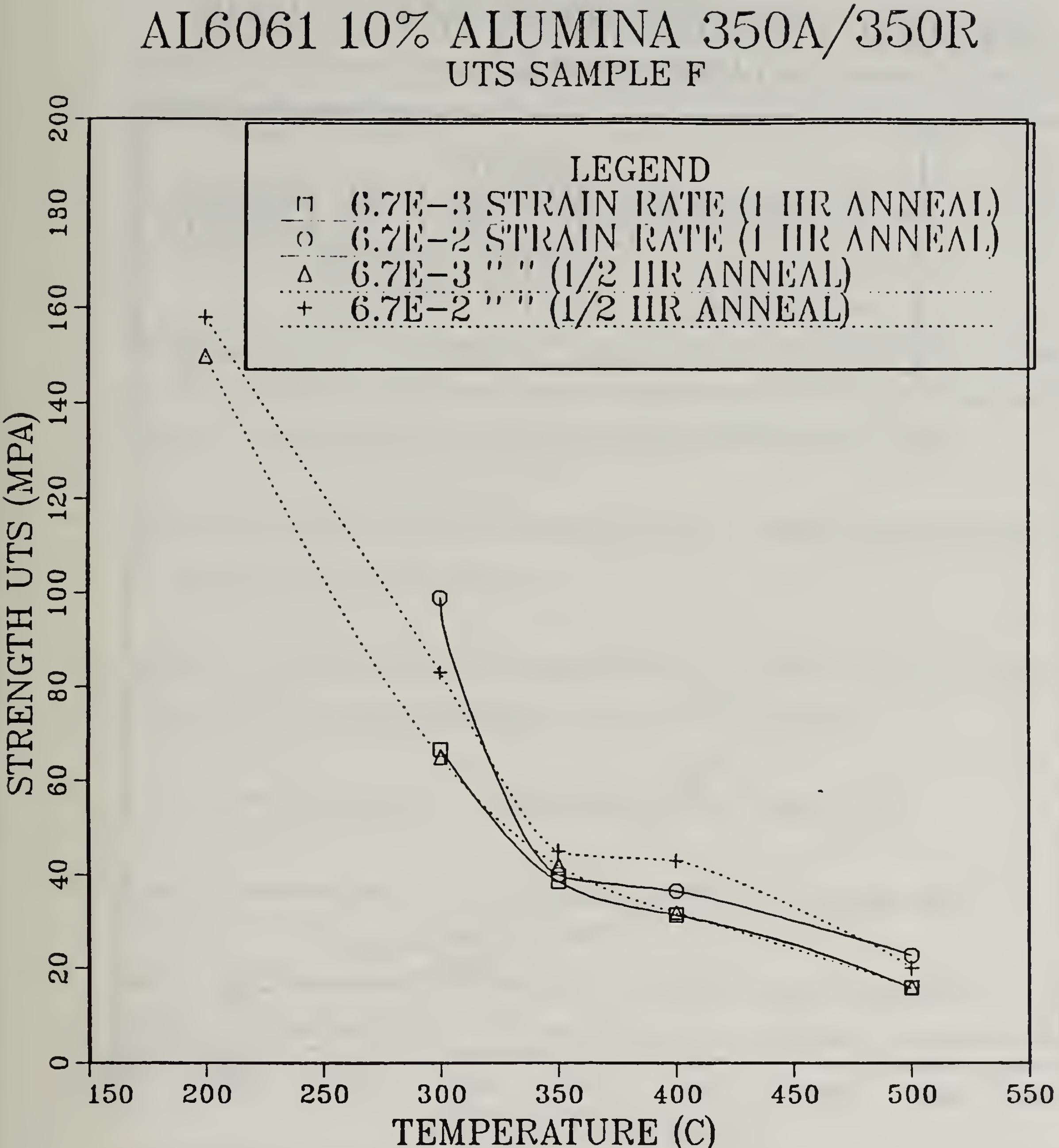

Figure 36. Ultimate strength vs. temperature, sample F, 10 vol. pct. Alumina.

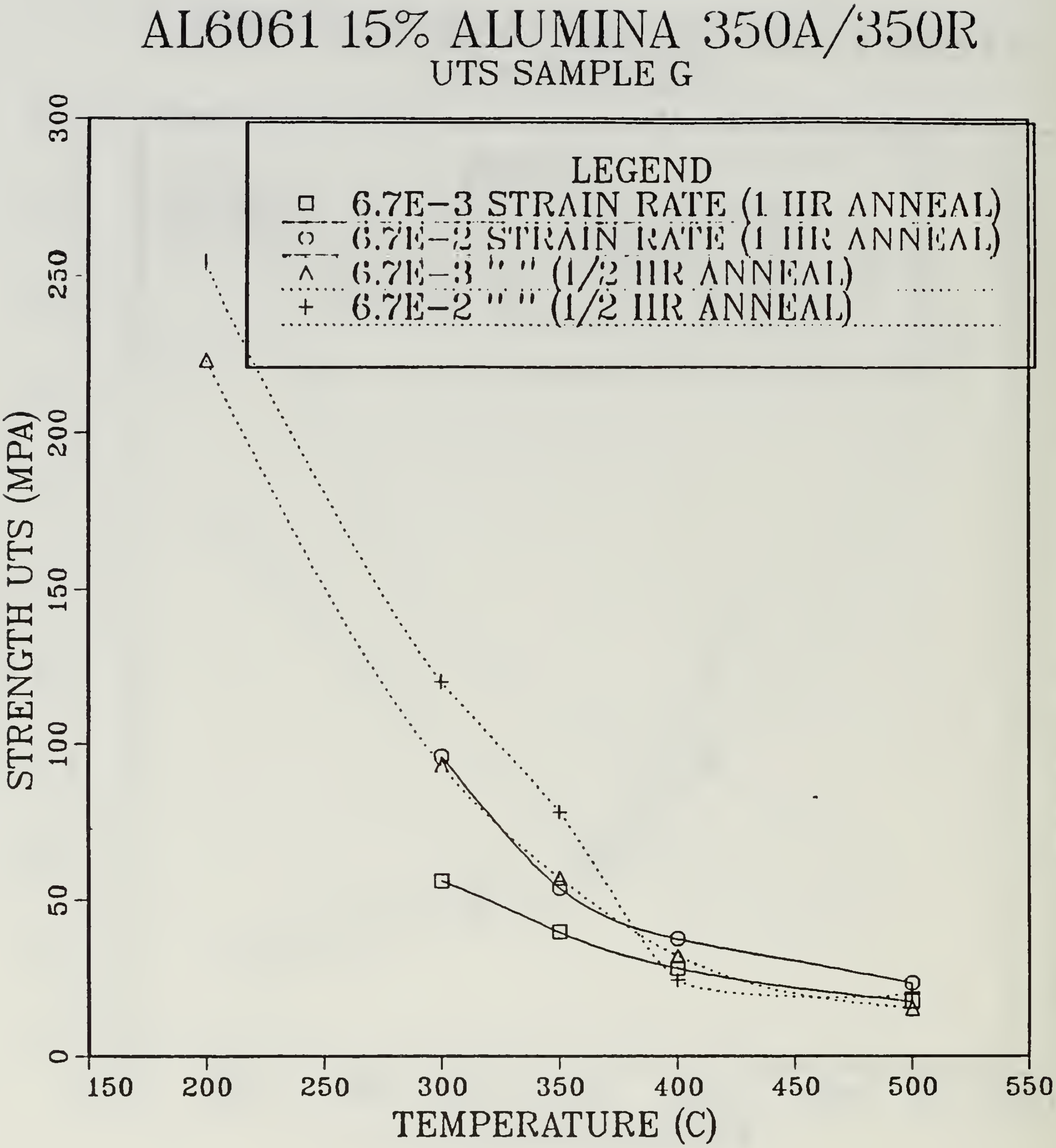

Figure 37. Ultimate strength vs. temperature, sample G, 15 vol. pct. Alumina.

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